SOIL SCIENCE

Contents

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THE RÔLE OF SILICA IN COUNTERACTING MAGNESIA-INDUCED TOXICITY

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Numerous studies have shown that unsupplemented additions of either magnesium oxide or precipitated magnesium carbonate are likely to produce decided and even lethal toxicity upon plant growth. MacIntire, Willis and Hardy (2) showed that a heavy treatment of "fluffy" precipitated magnesium carbonate was quickly fixed in silicate form in a loam soil and that decided toxicity was in effect for a considerable period after the disappearance of the carbonate. MacIntire and Young (2) later showed that the initial toxicity disappeared and that a beneficial effect followed. This transition occurred in spite of a large residual of fixed magnesia, the change in effect upon plant growth being attributed to the influence of "aging," or conversion into more complex and less soluble compounds. It was further pointed out that this phenomenon would be more characteristic of loams and soils high in colloidal silica and silicates than of soils relatively poor in these constituents. Shollenberger (4) also showed that the "light" magnesium carbonate was more quickly and extensively fixed than an equivalent quantity of "light" precipitated calcium carbonate.

Because of the previously determined extensive absorption of MgO from the carbonate forms, it was thought possible that hydrated SiO_2 would react with added MgO, thereby removing it from the active sphere and thus minimizing toxicity. This assumption led to a study of the effect produced by additions of silica along with MgO, using the same type of soil which was studied in the previously reported cylinder work.

Silica was added to soils by Shedd (6) as a control on the silica content of calcium silicate and magnesium silicate treatments, but not for the purpose intended in the present work. Schollenberger (5) likewise studied the possible value of the silica content of calcic-siliceous materials and used "air-dry hydrated silica plus dialyzed silica," but no consideration was given to absorptive or eliminative properties. Jennings (1) in attacking the problem of the assimilation of silica by the plant, used a silica gel as a medium for the growth of wheat seedlings.

EXPERIMENTAL

The observations given in this paper were obtained as results from six of thirty-six 1/2000-acre outdoor embedded concrete frames similar to those in

331

use at the Cornell station and shown in plate 1. Tobacco was used as the crop.

An excavation was made to a depth of 30 inches.   Re-enforced concrete walls were poured and, after setting, primed with creosote and then heavily coated with hot pitch.   Red clay subsoil from under a nearby Cumberland loam was then placed.   A pile sufficient for 1-inch depth in all 36 frames was thoroughly mixed and the first 1-inch layer placed in each frame, July 13, 1922. This procedure was repeated until a depth of 12 inches had been made in all frames by August 4, 1922.   The total weight of the 12 layers of subsoil in each 1/2000-acre frame was 1357.9 pounds, moisture-free basis.   The surface-soil placement of 9 layers was then made in the same manner, August 10, 11 and 12. The surface soil was disced, harrowed, rolled and again disced before screening The total weight of soil, moisture-free basis, was 1228.9 pounds in each 1/2000-acre frame.   After placement the soil was allowed to settle until May, 1923. Treatments of 500 pounds of 15 per cent acid phosphate and 100 pounds of muriate of potash per acre were made May 3, 1923.   Magnesium oxide, at the rate of 8000 pounds CaO-equivalence per acre-surface, was added to each of 6 frames.   Two frames received only the fertilizer and MgO, 2 other frames received in addition hydrated, precipitated silicic acid at a rate of 4 tons of SiO_2 per acre, and the remaining 2 frames, at a rate of 16 tons per acre.   The silicic acid contained 26.9 per cent H_2O as absorbed moisture and water of hydration.   All of the treatments were harrowed thoroughly throughout the upper $2\frac{1}{2}$ inches of soil.   Six selected tobacco plants were set in each of the frames May 25, 1923, giving 12 plants for each treatment.   Considerable difficulty was experienced in securing a stand in frames 16A and B, where MgO was added without silica.   Re-setting of different plants in frames 16A and B MgO alone, was done 4 times prior to July 5.   On this date the fifth and final re-setting resulted in the full number of 12 plants for the MgO frames.   Top-dressings of $NaNO_3$ solution were made at the rate of 100 pounds per acre with equal amounts to each plant on May 25 and again at the rate of 80 pounds, July 3, 1923.

EFFECTS ON PLANT GROWTH

The plants of the 6 frames were photographed July 13 (plate 2), and harvested September 8, 1923.   The total growth is given in table 1.   The weights include both suckers and fallen leaves.

From the photo (plate 2) it is evident that the silicic acid served to decrease the toxicity induced by the added MgO.   The roots from the soils treated with MgO were characterized by a mass of fine hair rootlets.

After the removal of the entire plants, the frames were seeded to clover September 12, 1923; but, because of the late and unfavorable season, no stand was obtained; the soil, therefore, remained fallow over winter.

The 1924 tobacco plants were set as before, on June 6, and harvested September 12.   No additional fertilization was given except for top-dressings of

the $NaNO_3$ solution at 100-pound and 80-pound rates, July 16 and 23 respectively. The soil was prepared for the setting of plants without being turned. The growth of the second year is recorded in table 1, and shown as of August 11, by the photos of plate 3. Much better growth was again obtained where silica was added and it is evident that the added silica continued to exert a buffering effect upon the MgO addition.

TABLE 1

Growth of entire tobacco plants, first crop, second crop and total as influenced by MgO additions, *with and without supplements of hydrated silicic acid*

FRAMES	TREATMENT	AIR-DRY WEIGHT OF ENTIRE CROP, PER PAIR OF FRAMES		
		1923[†]	1924	Total
		gm.	gm.	gm.
1A and B	None	1,382	801	2,183
16A and B	MgO alone	1,270	618	1,888
17A and B	MgO and SiO_2, 4 tons	1,639	983	2,622
18A and B	MgO and SiO_2, 16 tons	1,791	932	2,723

* 8000-pound CaO-equivalent constant.

† Including suckers and fallen leaves.

TABLE 2

Increase in carbonates from additions of 4 tons of MgO with and without supplements of hydrated silicic acid after an interval of 17 months

TREATMENT	INCREASE AS	
	CO_2	$CaCO_3 \backsim$
	per cent	per cent
MgO, $\backsim$ 4 tons CaO	0.104	0.2364
MgO, $\backsim$ 4 tons CaO plus SiO_2, 4 tons	0.049	0.1114
MgO, $\backsim$ 4 tons CaO plus SiO_2, 16 tons	0.016	0.0364

MgO FIXATION AND CARBONATION

It will be remembered that since the MgO and other treatments were mixed throughout only the upper $2\frac{1}{2}$ inches of soil, the treatments were on the basis of approximately 700,000 pounds of soil instead of 2,000,000 pounds. Even with intensive mixing, the incorporations were not perfectly disseminated throughout the surface depth. Furthermore, the surface area was often so dry as to preclude maximum reaction between MgO and soil, and magnesia and added silica. It would be expected, therefore, that a part of the added MgO would still be present as either the hydroxide or carbonate. In order to ascertain the effect of silica additions upon the extent of carbonate accumulation, samples of the treated zone and lower depth were taken, immediately dried, sealed and analyzed for carbonate CO_2, October 1, 1924. The surface-zone results, corrected for the small amount of CO_2 evolved by the action of the liberating acid upon the acid soil, are given in table 2.

The data of table 2 showed that there was a definite increase in the carbonate content of the soil treated with MgO alone. Carbonate determinations also showed that, as a result of the surface treatment, no accumulation of carbonates had occurred in the lower zone of the surface soil. Schollenberger (4) showed that an addition of MgO resulted in an increase of the carbonate content of a soil which had practically completely disintegrated a chemically equivalent amount of "light" precipitated magnesium carbonate.

But the data of table 2 also show that the occurrence of $MgCO_3$ in the surface zone was materially diminished by the 4-ton silica treatment and still more so by the 16-ton addition. The silica could not exert a direct retardative effect upon the speed of carbonation; it is, therefore, apparent that either, (a) the added SiO_2 combined with a large part of the added MgO after its hydration, leaving but a small part to undergo reversion to the carbonates, or (b) the MgO underwent hydration, with minimum reaction with soil, and then carbonation, after which reaction between $MgCO_3$ and SiO_2 ensued. As previously stated, imperfect mixing, the periodic dry condition of the surface zone and the relative insolubility of both $Mg(OH)_2$ and SiO_2 militated against direct and complete reaction between the oxide or hydroxide form of magnesium and silica. Assuming that the MgO underwent hydration and subsequent carbonation, and admitting the ready solubility of $MgCO_3$ in carbonated water, it still obtains that the dry condition which often prevailed in the surface zone of the soil would not have been favorable for the movement of $MgH_2(CO_3)_2$ through the surface zone containing the localized occurrences of added silica.

There is one additional point of interest, that of the completeness of the carbonation of that portion of the MgO which had not been fixed by the soil. To determine this point, 25-gm. charges of the soil samples of table 2 were brought to a moist condition in a granular state and exposed to an atmosphere of CO_2 for periods of 18 and 24 hours. The charges were then dried in an oven at 100°C. and analyzed for carbonate CO_2. The analyses made after both periods of exposure failed to show any increase in carbonate CO_2. It is therefore proved that all the applied oxide of magnesia had been converted to the carbonate or silicate combinations.

From the foregoing it is evident that the added hydrated silica combined with the added MgO or its hydrate or carbonate derivatives, and that such combination served to decrease the solubility and toxicity of the alkali-earth. It is also apparent that the larger silica additions were more effective than the smaller ones in this regard. From this it may be concluded that the hydrated silica content of a soil is a potent factor in controlling the effect which will be produced by the addition of MgO in the oxide, hydrate or carbonate forms.

SUMMARY

Magnesia-induced toxicity and the buffering effect of silica were studied by means of tobacco grown in 1/2000-acre concrete frames.

MgO alone, equivalent to a rate of 8000 pounds of CaO per acre, was found to be toxic to tobacco, especially during the early stages of growth.

Silica at the rate of 8000 pounds SiO_2 per acre was found to decrease toxicity while still greater effect was produced by 32,000-pound additions.

Decreased toxicity was apparently caused by chemical combination between MgO and SiO_2, the increase in $MgCO_3$ residuals having been practically nil when the heavy addition of SiO_2 was made.

All of the added MgO had passed to either the carbonate or silicate forms after the harvesting of the second crop.

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PLATE 1

PITCH-COATED RE-ENFORCED CONCRETE FRAMES BEFORE PLACEMENT OF SUBSOIL AND SOIL

336

338

W. H. MACINTIRE, W. M. SHAW AND J. B. YOUNG

FIG. 1

FIG. 2

FIG. 3
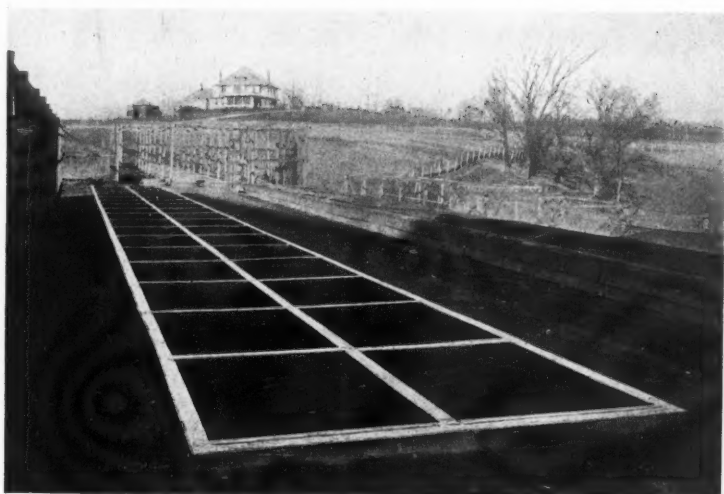
TOXICITY INDUCED BY ADDED MgO AND AMELIORATION CAUSED BY ADDITIONS OF HYDRATED
SILICA AFTER 66 DAYS GROWTH OF SECOND CROP OF TOBACCO

Fig. 1. Frames 16A and B.   MgO ⇌ 4 tons CaO per acre.
Fig. 2. Frames 17A and B.   MgO ⇌ 4 tons CaO per acre, plus 4 tons SiO_2.
Fig. 3. Frames 18A and B.   MgO ⇌ 4 tons CaO per acre, plus 16 tons SiO_2.

W. H. MACINTIRE, W. M. SHAW AND J. B. YOUNG
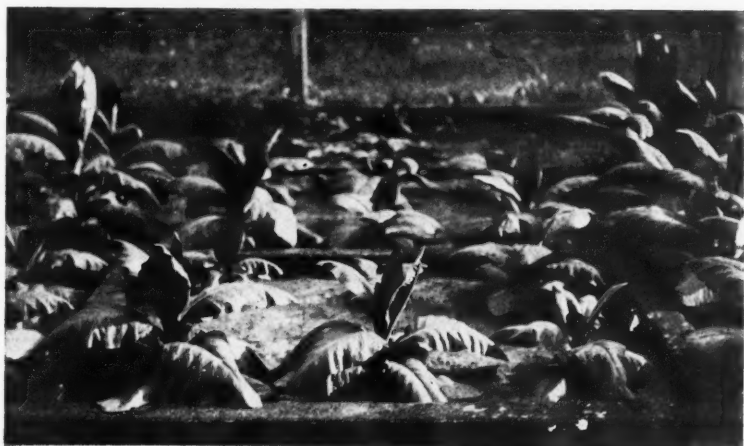
FIG. 1

FIG. 2

FIG. 3
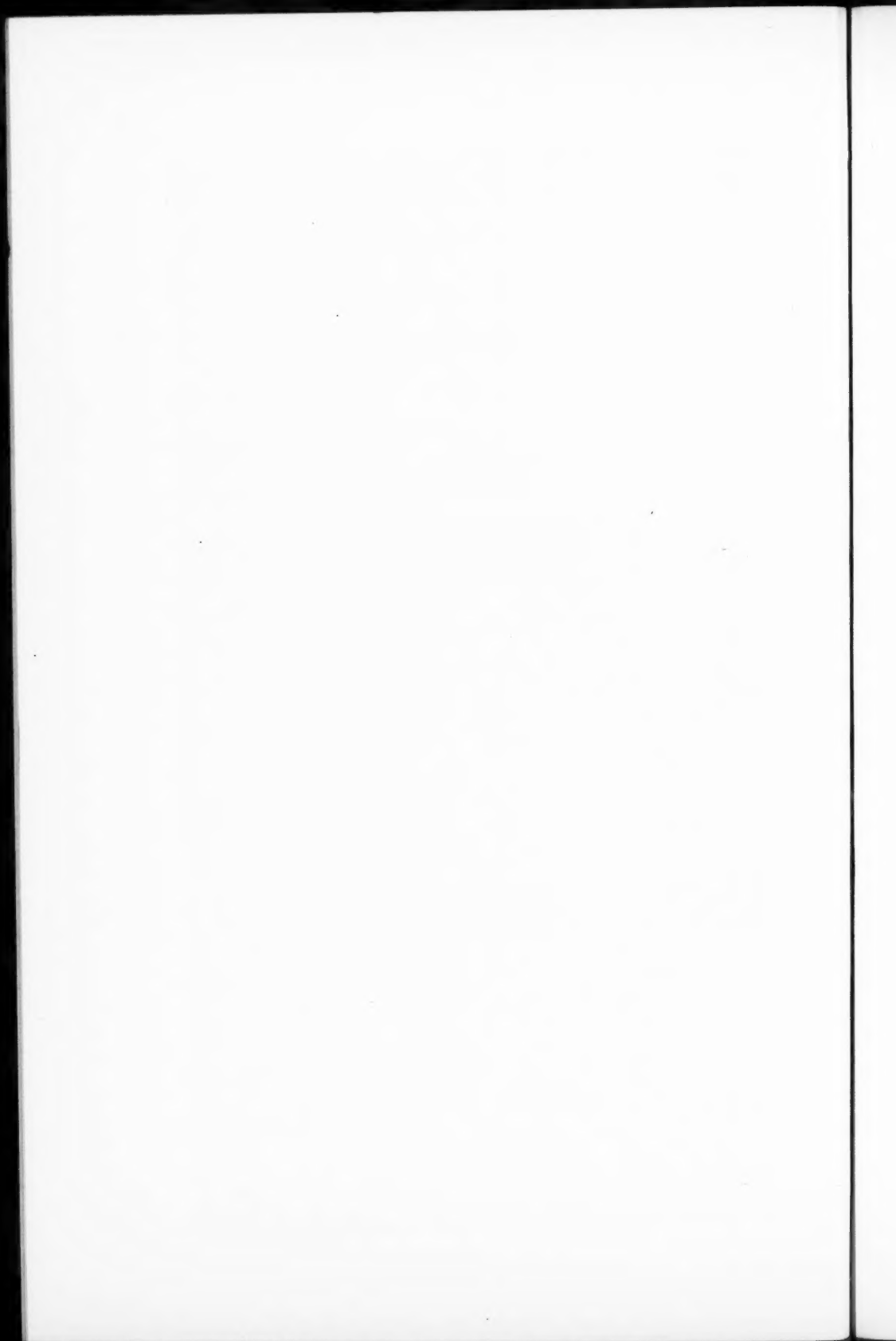
THE EFFECTS OF ALKALI SALTS ON BACTERIOLOGICAL ACTIVITIES IN SOIL: I. AMMONIFICATION[1]

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The reclamation of natural alkali soils and the prevention of soils now in cultivation from becoming impregnated with alkali salts are problems of great importance in irrigated districts of the semi-arid Northwest. This practical struggle with the alkali salts and the fear of soils becoming "salted out" have led to a study of the effect of these salts on various crops and on bacteriological activities in soil. The earlier investigations of the tolerance of crops to the salts were based on additions of various salts to the soil, with the assumption that the added amount represented the concentration actually affecting the plant. Later investigations on the toxicity of the various salts to the crops were based on the amount of salt recoverable in the water extract of the soil. These later studies showed that added salts were only partly recovered in the aqueous extract, consequently the tolerance to total water-soluble salt was not the same as was concluded from salt additions.

Headley, Curtis and Scofield (4) pointed out that sodium carbonate added to the soil and allowed to remain several weeks is only partly recovered in the water extract of the soil. They found that the percentage recovered from a loam soil was smaller than from a sandy soil.

Harris and Pittman (3) pointed out the discrepancy between the amount of added alkali salts and that recovered in the water extract after such additions. They also found greater injury to plants grown in sand than to those grown in a loam soil after each received the same amount of sodium carbonate.

Kearney (5) found that chloride and carbonate added to the soil gave a higher percentage recovery of chloride than carbonate in the water-soluble extract.

Neidig and Magnuson (9) have made a thorough investigation of the equilibrium of sodium carbonate and bicarbonate when applied to soil and have shown that the soil solution reaches an equilibrium within a relatively short period after the addition of sodium carbonate and bicarbonate, and that this equilibrium is again reached after a short period following the addition of a second portion of the carbonate.

Rather extensive studies have been made of the effects of various salts on bacteriological activities in soil. Such salts as the carbonates, chlorides, sulfates, and nitrates of sodium, calcium, magnesium and iron have been tested. In all cases the investigations are based on the addition of a certain amount of salt and in no case deal with amounts of salt recovered in water-soluble extracts of the soil.

Lipman (6) was the first to point out the effects of alkali salts on bacteriological activities. He found that sodium chloride was toxic to ammonia formation in solution by *B. subtilis*, and that this toxicity was reduced by additions of magnesium or potassium chloride. He later (7) carried the investigation to soil and determined the effects of sodium carbonate, chloride, and sulfate on ammonia formation. The carbonate was found to stimulate in concentrations as high as 1.0 per cent, while 0.2 per cent sulfate reduced ammonia formation nearly one-half, and 0.2 per cent chloride reduced it approximately two-thirds. In a later contribution (8) he pointed out an "antagonistic" action between sodium carbonate, sulfate, and chloride. Sodium chloride in a concentration of 0.2 per cent (added salt) was found toxic to ammonia formation but this toxicity was gradually reduced by additions of sodium sulfate up to 0.3 per cent. Sodium carbonate was found to overcome this toxicity at 0.3 per cent and to stimulate in concentrations from 0.4 per cent to 1.0 per cent. Sodium sulfate was toxic in a concentration of 0.9 per cent but the carbonate reduced this toxicity.

Greaves (2) determined the effects of sodium carbonate, sulfate, and chloride on ammonia formation in a sandy loam soil. Sodium chloride stimulated ammonia formation in concentrations of 0.0009 to 0.0018 per cent, but was toxic above the latter amount. The sulfate was employed in concentrations from 0.0011 to 1.55 per cent, and was toxic throughout. The carbonate stimulated in concentrations from 0.00083 to 0.532 per cent; concentrations of 0.637 per cent and above were found toxic.

PURPOSE OF INVESTIGATION

All the investigations on the effects of alkali salts on bacteriological activities in soil have been based on the addition of definite amounts of the salts to the soil. Results have been obtained before these additions reached an equilibrium, before the soil solution was in any way constant. No absorption or adsorption, or chemical reaction in the soil removing or changing the added salt in the soil solution has been taken into consideration. Sufficient time

has not been allowed for the added salts to reach an equilibrium, and no comparison has been made of the effects of added salts and those recovered in the water extract. No consideration has previously been taken of the effect of duration of time on bacterial activities after additions of alkali salts. Likewise consideration has not been taken of the relation of recoverable salts in the water extract to the added salts in their effect on bacterial activities. A study of the effect of time and of water-soluble salt recovered at stated periods would throw additional light on the small amount of information now available on the effects of these salts on bacterial activities in the soil. The present investigation is undertaken to gain definite knowledge of these phases at different stages of equilibrium in the alkali-soil system.

PLAN OF EXPERIMENT

A neutral silt loam, light in color and of average fertility, located in the irrigated section of the southern part of the state, was chosen for the work. The sample was taken in an area which contained some alkali, but this particular sample was approximately neutral in reaction and the entire tract from which it was taken had never shown evidence of alkali. Several tons of the soil were shipped to the experiment station and stored in a dry building.

The experiments were arranged to determine the tolerance of plants to alkali salts based on the quantity of recoverable salt from the water extract of the soil and the total added salt, and a correlation of these results with bacteriological activities in the soil. Prior to the initiating of the bacteriological studies, the soils were chosen and the chemical work done by the department of agricultural chemistry as is indicated in footnote 1.

Forty-eight-pound samples of the soil were weighed out and the salts added in dry form. Each sample was thoroughly mixed with its portion of salt and placed in a 4-gallon jar. The moisture was brought to approximately 20 per cent by weight. In each pot 12 kernels of Bluestem wheat were planted and after germination were thinned to 6 plants. The crop was allowed to mature and was then harvested and the yield recorded. The soils were then turned out of the pots, thoroughly mixed, returned to the pots and again seeded to wheat. The second crop was harvested after maturity. Samples were taken for the determination of bacterial activities and chemical analyses after a few days contact of salt and soil, again after the first crop was harvested, and again after harvest of the second crop. In this way any adsorption, absorption, or reaction of the soil in removing salt from the water-soluble fraction could be correlated with plant growth and bacterial activities at these stated periods.

The general plan of treatment of the various pots is shown in tables 1, 2 and 3. All treatments were made in triplicate, two pots of each treatment being planted to wheat, and one allowed to remain as an uncropped control.

METHODS

The bacteriological studies consisted of the determination of ammonia formation from blood, and nitrate formation from ammonium sulfate. The ammonia formation was determined as follows: portions of moist soil equivalent to 100 gm. oven-dry soil were weighed in duplicate into 500-cc. widemouth bottles. To each portion 1 gm. of finely divided dried blood was added, thoroughly mixed with the soil, and the moisture content brought to 20 per cent, allowing an additional 2 gm. of water for the 1 gm. of blood. The bottles were then loosely stoppered with cotton and incubated at 28°C. for 24 hours. At the end of this time they were thoroughly stirred to insure equal distribution of moisture, and reincubated for 6 days. They were then analyzed for ammonia content by the aeration method as outlined by the authors (1). Chemical analyses for water-soluble salts were made by Neidig and Magnuson (9).

This paper deals only with the effects of the salts on ammonification and the chemical analyses. The effects on nitrification and the correlation with crop-yield studies are presented in parts II and III of this series.

RESULTS

The salts were added to the soil on July 11, 1921, and the first samples taken the following day. The analyses for salt content were made after 10 days. The samples were not available for bacteriological tests for 15 days after sampling, a contact of salt and soil being allowed for 15 days. The second samples were taken after 9 months and 17 days, and the third samples were taken after 14 months and 25 days. In order to have a series comparable with other data available on the effects of alkali salts on bacterial activities, another series was added known as the "initial series." This series was obtained by weighing 100-gm. portions (oven-dry basis) of the untreated soil into the 500-cc. bottles, adding 1 gm. of blood and mixing thoroughly, then adding the alkali salts from standard solutions giving the same concentration represented in the pots. From this point they were treated in the same manner as the other ammonification tests. This gave a series showing the effects of the salts when added the day the ammonification experiment began, an "initial series."

Unfortunately the ammonification tests on the first sampling were lost, due to an attempt to determine ammonia by the magnesium oxide, copper flask distillation, a method found to give unreliable results. The salt-recovery data at the first sampling period are shown in the figures. These give ammonification data from the "initial" series, second sampling, hereafter called "second period" (9 months and 17 days), and the third sampling, called "third period" (14 months and 25 days).

All the data presented in the tables and figures, with the exception of the initial series, are from wheat-cropped pots. Data obtained from the non-crop

check, and also from an alfalfa series, none of which are shown here, are taken into consideration in making deductions and drawing conclusions. The results from these other series are similar to the results of the wheat series and are, therefore, not presented separately.

Single-salt treatments

The effects of the salts in single application on ammonia formation from blood at the various periods of the experiment, together with the salt recoveries at the same periods, are shown in table 1. These also are represented graphically in figure 1. The data are expressed in percentages, the controls being

TABLE 1

Effects of alkali salts on ammonia formation in soil

Single-salt treatments

TREATMENT		INITIAL	SECOND SAMPLING		THIRD SAMPLING	
		Ammonification	Ammonification	Salt recovery	Ammonification	Salt recovery
	per cent	*per cent*	*per cent*	*per cent of soil*	*per cent*	*per cent of soil*
None..............................		100.0	100.0	0.031	100.0	0.046
Na₂CO₃	0.2......................	100.8	98.2	0.094	125.0	0.111
	0.4......................	102.1	110.3	0.141	118.5	0.169
	0.6......................	97.3	100.9	0.195	141.0	0.210
	0.9......................	101.0	116.9	0.317	134.0	0.321
NaCl	0.1......................	54.5	89.0	0.123	96.6	0.081
	0.2......................	41.9	69.5	0.214	104.6	0.131
	0.4......................	35.3	68.1	0.281	108.4	0.118
Na₂SO₄	0.2......................	51.6	86.4	0.209	108.4	0.233
	0.4......................	59.6	83.7	0.422	110.5	0.384
	0.6......................	52.4	78.5	0.563	111.0	0.499
	0.9......................	49.6	62.4	0.780	106.5	0.687

considered as 100 per cent. The salt-recovery data are expressed in terms of the sodium salt and given in percentages of the anhydrous soil.

The data in table 1 and figure 1 show that additions of sodium carbonate in concentrations from 0.2 per cent to 0.9 per cent have had little effect on ammonia formation at the initial period. These concentrations of carbonate at the second period in the water-soluble extract become 0.094 to 0.317 per cent and markedly stimulate ammonia formation. At the third period the concentrations become 0.111 to 0.321 per cent and still more markedly stimulate ammonia formation. At this last period 0.111 per cent of the carbonate, expressed as the sodium salt, give a stimulation of 25 per cent in ammonia formation, which increases to a stimulation of 41 per cent in the presence of 0.210 per cent of the salt. Thus we see a more marked stimulation at the third

period from approximately the same or even higher concentrations of carbonate than at the previous periods. Approximately one-half to one-third of the
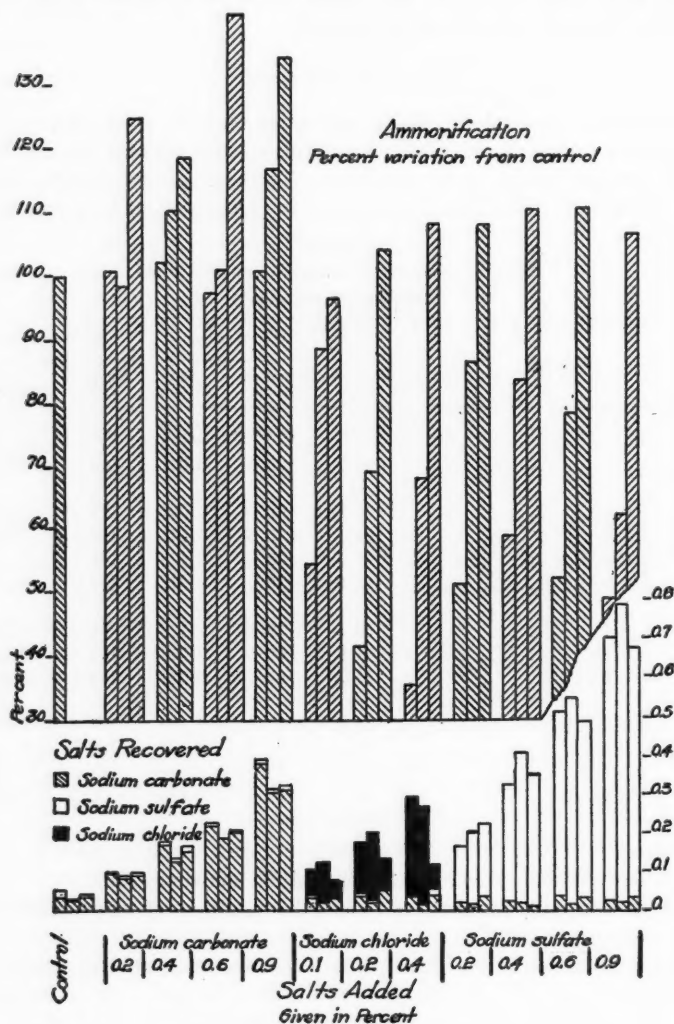
FIG. 1. SINGLE-SALT TREATMENTS

added carbonate is recovered in each case at the second period and a slightly higher percentage is recovered at the third period. The increased stimulation at the second and third periods may be accounted for by the equilibrium of

added salt.   The first effect is due largely to the sodium salt, but as time goes on there is probably an interchange of bases which decreases the amount of sodium ions present in the solution.   There also is a possibility that the organisms become more tolerant as time progresses.

The effect of the carbonate on ammonia formation is in accord with the results of Lipman who found that additions of 0.05 per cent to 1.0 per cent were stimulating.   Greaves found additions from 0.00083 per cent to 0.532 per cent stimulating while additions from 0.637 to 1.168 per cent proved toxic.

We find from the data that sodium chloride in the concentrations employed is toxic to ammonia formation in the initial series and still toxic at the second period.   There is a gradual decrease in toxicity with time until a slight stimulation is noted at the third period.   In the initial series 0.1 per cent added sodium chloride reduces the ammonia formation approximately one-half, while 0.4 per cent reduces it about two-thirds.   At the third period we find a slight stimulation in concentrations of 0.131 per cent and 0.118 per cent. The results of the "initial" series are in accord with those of Lipman and also of Greaves.   Greaves found 0.0036 per cent of the added chloride toxic. The toxicity recorded by these investigators might have assumed different proportions had sufficient time been allowed for the formation of an equilibrium.

The chloride recovery in the water extract of the soil does not follow the same curve as the carbonate recovery.   In the case of the carbonate we find a greater salt recovery at the third than at the second period while with the chloride we find a decrease in recovery at each succeeding period although the percentage recovery is higher than with the carbonate.   This removal of the active chloride is accompanied by a decrease in toxicity.   It is interesting to note that 0.1 per cent added chloride in the "initial" series reduced ammonia formation nearly 50 per cent, while the pot receiving 0.4 per cent, and giving a recovery of 0.118 per cent at the third period, showed no toxicity at that period.   At the second period a salt content of 0.281 per cent sodium chloride, after the addition of 0.4 per cent, gave an ammonia accumulation of 68.1 per cent, much better than an application of 0.1 per cent in the initial series.   These results cannot be explained by chloride absorption because concentrations stimulating or having little or no effect at the third period are greater than are found toxic in the "initial series."   The decreased toxicity at the second and third periods is probably due, in part at least, to interchange of basic ions.   The chloride was applied at the start in the form of the sodium salt but probably was recovered at the later periods as a mixture of basic ions with chlorine.   The mixture of the basic ions would probably prove less toxic than an entire concentration of one of the salts.   There also is a suggestion of development of tolerance on the part of the organisms.   It also will be observed in figure 1 that there is a slight loss of chloride at the second and particularly the third period.

We find sodium sulfate toxic in all concentrations in the initial series,

reducing the ammonia formation approximately 50 per cent. This toxicity is less apparent at the second period. At the third period all concentrations cause an increased ammonia formation. The salt recovery at the third period is slightly less than at the second period. A larger percentage of the added sulfate than of either chloride or carbonate was recovered. We find concentrations from 0.23 to 0.68 per cent sodium sulfate stimulating ammonia formation at the third period whereas 0.2 per cent of the salt was very toxic in the initial series. These results, similar to those obtained with the chloride,

TABLE 2

Effects of alkali salts on ammonia formation in soil

Double-salt treatments

TREATMENT			INITIAL	SECOND SAMPLING		THIRD SAMPLING	
Na_2CO_3	NaCl	Na_2SO_4	Ammonifi-cation	Ammonifi-cation	Salt recovery	Ammonifi-cation	Salt recovery
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent of soil*	*per cent*	*per cent of soil*
...	....	...	100.0	100.0	0.031	100.0	0.046
0.1	0.10	...	58.8	83.7	0.128	106.0	0.100
0.3	0.05	...	82.0	91.6	0.164	118.4	0.146
0.1	0.30	...	36.5	74.4	0.256	98.2	0.147
0.6	0.10	...	81.4	82.0	0.292	136.8	0.252
0.2	0.20	...	63.2	79.4	0.184	112.4	0.150
...	0.05	0.2	47.9	82.6	0.222	99.4	0.190
...	0.30	0.1	48.3	78.5	0.326	86.0	0.221
...	0.10	0.4	56.5	83.1	0.405	90.0	0.404
...	0.10	0.6	52.0	79.0	0.527	88.7	0.554
0.1	....	0.1	75.6	87.1	0.172	109.6	0.130
0.2	....	0.2	74.0	92.0	0.234	108.0	0.228
0.3	....	0.4	78.2	87.9	0.299	95.0	0.338
0.2	....	0.6	68.6	76.8	0.570	92.7	0.555
0.6	....	0.1	98.0	89.2	0.279	128.0	0.269
1.0	....	0.1	95.4	97.0	0.426	132.0	0.412

indicate a possible readjustment of basic ions and a tolerance of the organisms after prolonged exposure to the salt. Lipman found applications of the sulfate between 0.2 and 2.0 per cent toxic to ammonia formation, and Greaves found very small amounts toxic. The results of these investigators are comparable with the initial series above.

Double-salt treatments

The effects of combinations of two salts on ammonia formation in the soil and the salt recovered at the various periods are shown in table 2 and represented graphically in figure 2. The results of ammonia formation are expressed in percentages, the control being considered as 100 per cent.

From the results in table 2 and figure 2 we find a gradual decrease in toxicity as time progresses. All concentrations and combinations of salts were toxic

Ammonification
Percent variation from control

Salts Recovered
■ *Sodium carbonate* □ *Sodium sulfate* ■ *Sodium chloride*

Salts Added
Given in Percent
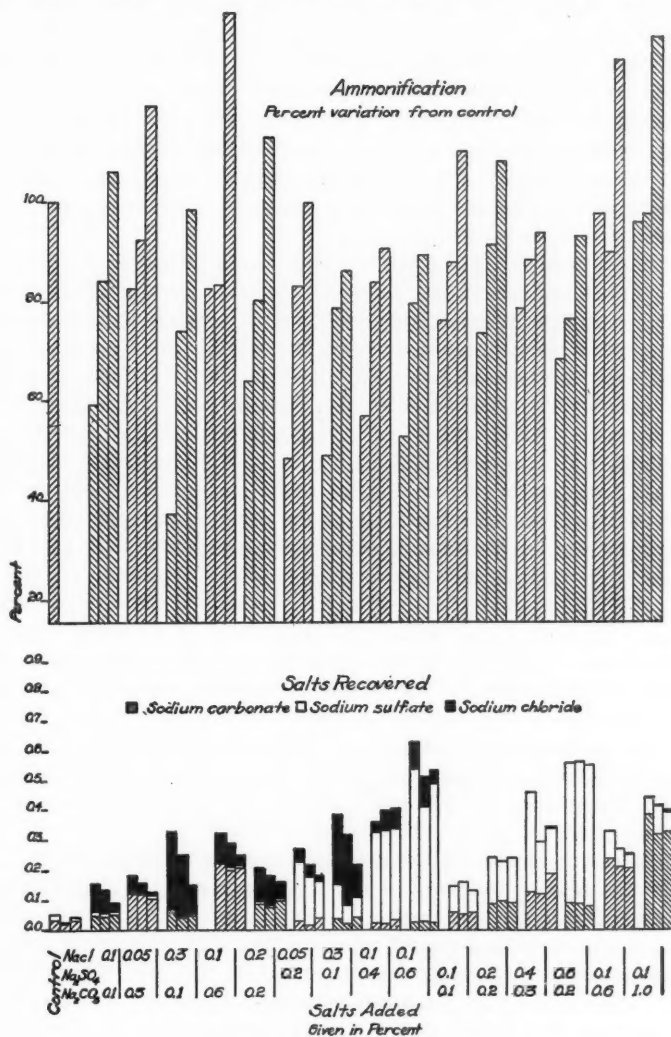
FIG. 2. DOUBLE-SALT TREATMENTS

in the "initial" series, and in no case was this toxicity entirely overcome at the second period. In about half the combinations the toxicity was overcome at the third period. Referring to the single-salt treatment shown in table 1

and figure 1, we find all concentrations of the carbonate stimulating at each period including the "initial," and all concentrations of chloride and sulfate toxic in the "initial" and second periods, and stimulating in the third. We now find additions of 0.1 per cent each of carbonate and chloride toxic in the "initial" and second periods, likewise all other combinations of carbonate and chloride. A stimulation in all cases but one is noted in the third period. This stimulation can be explained from the results of the single-salt treatments, in which it is noted that carbonate and chloride, as single salts, stimulate at the third period. This stimulating effect is not so great as with the carbonate alone. The carbonate has a tendency to decrease the toxicity of the chloride in the initial period.

We find in table 1 that all concentrations of sulfate are toxic in initial and second periods and stimulating in the third period. We now find in table 2 that carbonate slightly decreases the toxicity of the sulfate in the initial period. The total salt recovery at the third period, after addition of 0.6 per cent sulfate (table 1) was 0.499 per cent, practically all sulfate, and this stimulated ammonia formation. The total salt recovery at the third period, after the addition of 0.3 per cent carbonate and 0.4 per cent sulfate (table 2) was 0.338 per cent and this gave a decrease in ammonia formation. The carbonate stimulated ammonia formation in all periods when used alone, and the 0.384 per cent sulfate increased ammonia formation at the third period when used alone, and now we find the combination of carbonate and sulfate toxic at a lower total salt concentration than was found stimulating when each was applied alone. This indicates an absence of any antagonistic action over any length of time. Any antagonism which might be apparent in the initial series has disappeared in the second and third periods. It is interesting to note that additions of 0.4 per cent and 0.6 per cent sulfate were not toxic at the third period when applied alone, giving a recovery of 0.384 and 0.499 per cent, but these two concentrations were toxic at the same period when applied with 0.3 and 0.2 per cent carbonate respectively. There is practically no difference in these two cases in the total salt recovery. The tolerance for the sulfate seems not to develop in the presence of the carbonate.

In the sulfate-chloride combination the toxicity of either salt is not overcome by the other in the initial, second, or third periods. At the third period the ammonia formation is still materially below the control. This is interesting because we find in table 1 that all concentrations of chloride except one, and all concentrations of sulfate were stimulating at the third period when applied alone. The combination of the two salts seems to enhance the toxicity of each and cause it to persist after 15 months contact in the soil. This is not due to total water-soluble salt, as the concentration found toxic in combination at the third period was not so great as the concentration showing stimulation when applied separately at the third period. For example, we find in table 1 that the soil contains 0.687 per cent water-soluble salt at the third period after the addition of 0.9 per cent sulfate, and this stimulates ammonia for-

mation at that period. We now find from the data in table 2 that the soil contains only 0.404 per cent total water-soluble salt, largely sulfate, at the third period, after the addition of 0.1 per cent chloride and 0.4 per cent sulfate, but that this gives a reduction in ammonia formation. This indicates that the ammonia formation is not proportional to total salt concentration and that there is no antagonism of the salts, rather each salt increases the toxicity of the other, or the toxicity of the combination tends toward the sum of the toxicity of each separately at the third period.   These results are not in accord

TABLE 3

Effects of alkali salts on ammonia formation in soil

Triple-salt treatments

TREATMENT			INITIAL	SECOND SAMPLING		THIRD SAMPLING	
Na$_2$CO$_3$	NaCl	Na$_2$SO$_4$	Ammonification	Ammonification	Salt recovery	Ammonification	Salt recovery
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent of soil*	*per cent*	*per cent of soil*
....	....	....	100.0	100.0	0.041	100.0	0.046
0.05	0.05	0.05	72.6	107.3	0.084	107.6	0.088
0.01	0.10	0.10	72.5	102.5	0.228	100.4	0.166
0.20	0.10	0.10	72.8	93.0	0.226	104.2	0.232
0.40	0.05	0.10	88.7	93.9	0.331	112.6	0.236
0.60	0.10	0.20	80.8	.....	0.500	90.4	0.475
0.40	0.10	0.40	74.6	90.3	0.520	86.8	0.401
0.20	0.05	0.40	73.1	92.3	0.790	88.5	0.468
0.20	0.05	0.80	68.7	90.7	0.750	83.6	0.676
0.05	0.05	0.60	67.6	89.0	0.535	89.6	0.583
0.10	0.05	0.10	76.0	93.9	0.175	97.8	0.187
0.40	0.10	0.60	41.7	79.2	0.673	82.4	0.731
0.30	0.20	0.20	66.3	77.1	0.432	60.1	0.509
0.10	0.20	0.20	63.5	84.0	0.368	66.4	0.347
0.10	0.40	0.10	53.7	73.6	0.354	81.6	0.264

with those obtained by Lipman, and Lipman and Burgess, who found the toxic action of sodium chloride and sodium sulfate to disappear on addition of a combination of the two, or a combination of each with the carbonate. Their results however are comparable only with the initial series in this work.

Triple-salt treatments

The results of the triple-salt treatments are shown in table 3 and represented graphically in figure 3.   As in the preceding treatments the results are shown in percentages, the control being considered as 100 per cent.

In the figure we find a different type of curve than is found in the single- and double-salt treatments, namely a toxicity in the initial series, much less

toxicity in the second period, then an increased toxicity in the third period. This increased toxicity in the third period was not observed in the single
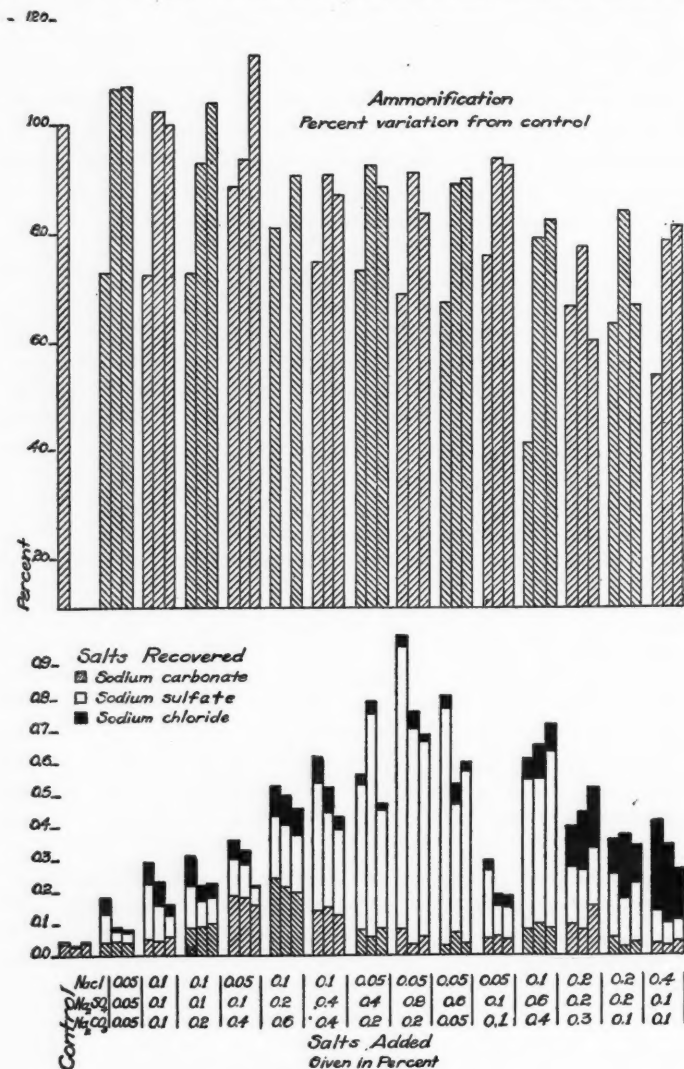
FIG. 3. TRIPLE-SALT TREATMENTS

treatments and in the double-salt treatments. Those pots which received a low total chloride and sulfate with a relatively higher carbonate have over-

come the toxicity at the third period and follow the curve found in the single- and double-salt treatments. The toxicity throughout in the initial and second periods is approximately that calculated by taking separately the average ammonia formation of the three treatments. The calculated effect obtained in the same way would show a stimulation in the third period, but there is a toxicity. The drop in the curve, low ammonia formation, at the third period is not due to total water-soluble salt. In some cases the total salt recovery is greater at the second than at the third period, and vice versa, and the yield of ammonia cannot be correlated with total salt recovery.

The chloride is the most toxic of the three salts and wherever it predominates there is a drop in ammonia formation. The sulfate is also toxic, but a total salt content of 0.75 per cent, largely sulfate, but in combination with a small amount of carbonate and chloride, gives a higher ammonia formation in the second period than a total salt content of 0.3 per cent, approximately half of which is chloride. Combinations of the three salts are in general no less toxic than the average of each salt alone in the same concentration in first and second periods, but these three-salt combinations are much more toxic than the average of each alone at the third period. There is no apparent antagonistic action in the second and third periods, and doubtful antagonism in the first period.

SUMMARY

A neutral silt loam was treated with various combinations of sodium carbonate, sodium chloride, and sodium sulfate, and the effects of these salts, singly and in combination, determined on ammonia formation in the soil. The effects were determined immediately after the addition of the salts, at the end of 9 months and 17 days, and again at the end of 14 months and 25 days. Chemical analyses for water-soluble salts were made at the three periods.

From original applications of 0.2 to 0.9 per cent sodium carbonate the carbonate recovery at the second period was 0.088 to 0.312 per cent, and at the third period 0.097 to 0.310 per cent.

Application of chloride from 0.1 per cent to 0.4 per cent gave a chloride recovery of 0.095 per cent to 0.257 per cent at the second period and 0.046 to 0.064 at the third period.

Applications of sulfate from 0.2 per cent to 0.9 per cent resulted in a sulfate recovery of 0.185 per cent to 0.755 per cent at the second period and 0.197 per cent to 0.652 per cent at the third period.

Combinations of the salts resulted in somewhat the same relative recovery at the two periods.

Sodium carbonate stimulated ammonia formation from blood at the initial period. This stimulation was more marked at each successive period.

Sodium chloride was toxic at the initial period but stimulating at the second and third periods. The toxicity was not directly proportional to the total salt recovery.

Sodium sulfate was toxic at the initial and second periods, but stimulating at the third period.   The toxicity was not directly proportional to the total salt recovery.

All combinations of two of the salts were toxic at the initial and second periods, but in many cases this toxicity was overcome at the third period. There was doubtful antagonism of the salts at the initial period and none at the second and third periods as measured by ammonification of blood. Combinations were often more toxic toward ammonia formation than would be expected from the results of the single-salt treatments.   Combinations of sulfate and chloride were toxic at the third period, whereas neither salt was toxic at the third period when applied alone.   No correlation could be made between toxicity and total recoverable water-soluble salt.

In the three-salt combinations there was in general a more marked toxicity at the third than at the second period.   Any toxicity resulting from the combination of the three salts could not be correlated with total recoverable water-soluble salt.   There seemed to be no antagonism of the salts in the second and third periods and doubtful antagonism in the first period as measured by ammonia formation.

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THE EFFECTS OF ALKALI SALTS ON BACTERIOLOGICAL ACTIVITIES IN SOIL: II. NITRIFICATION[1]

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The detailed plan of the experiment has been outlined in the ammonification study and the general plan of treatment of the pots is shown in tables 1, 2, and 3. This paper deals only with the effect of these salts on nitrate formation from ammonium sulfate as correlated with total recoverable water-soluble salt at the various periods.

Lipman (4) tested the effects of sodium chloride, sodium sulfate, and sodium carbonate on the nitrification of blood in soil. He reported a toxic action from the application of each salt. The actual points at which each of the salts became markedly toxic were 0.025 per cent for the carbonate, 0.35 per cent for the sulfate, and 0.1 per cent or less for the chloride.

Lipman and Burgess (5) pointed out an antagonism between sodium sulfate, sodium chloride, and sodium carbonate, as measured by the nitrification of blood in a sandy soil. Sodium chloride in a concentration of 0.2 per cent, found very toxic, was applied to the soil in combination with sodium sulfate in amount varying from 0 to 0.35 per cent, to determine the effect of these combinations on nitrate formation from blood. The sulfate overcame the toxicity of the chloride at 0.05 per cent and completely masked the toxicity through 0.25 per cent. The toxicity of 0.05 per cent sodium carbonate, which was quite marked, was overcome by the sulfate in concentrations from 0.2 per cent to 0.5 per cent. The toxicity of 0.35 per cent sodium sulfate, quite marked, was overcome by applications of sodium carbonate from 0.01 to 0.05 per cent inclusive. The marked toxic action of 0.05 per cent sodium carbonate was overcome by an application of 0.2 per cent sodium chloride. The authors conclude that "marked antagonism exists between the anions of Na_2CO_3, Na_2SO_4 and NaCl when a soil's nitrifying power is the criterion."

Brown and Hitchcock (1) tested the effects of alkali salts on the nitrification of ammonium sulfate in soil. They state that nitrification in normal soil is stimulated by small amounts of sodium chloride, and sodium sulfate, but that these salts become toxic at certain points varying with different soils. They found the toxic point of sodium chloride to be 0.02 per cent, sodium sulfate 2.0 per cent, and sodium carbonate 0.3 per cent.

Greaves (2) and associates tested the effects of alkali salts on the nitrification of blood in a sandy loam soil. Sodium chloride was found to stimulate nitrate formation in concentrations from 0.00036 per cent to 0.046 per cent, but was markedly toxic at 0.092 and 0.138 per cent. The sulfate applied in concentration from 0.00036 to 0.138 per cent was found toxic throughout, reducing nitrate formation 50 per cent. The carbonate in concentrations from 0.00036 to 0.138 retarded nitrate formation throughout. The authors state that the toxicity of sodium salts varies with the electro-negative ion with which it is combined and is due to physiological influence rather than osmotic pressure. In a later communication Greaves and Carter (3) pointed out the influence of moisture and soluble salts on nitrification. They found in general a maximum nitrate formation at 20 per cent moisture in the presence of sodium carbonate and sodium sulfate, and a maximum nitrate formation in the presence of sodium chloride at 30 per cent water. They conclude that "the relative toxicity of various salts to the nitrifying organisms decreased as the amount of water increased."

METHODS

Nitrification was determined as follows: Portions of moist soil equivalent to 100 gm. of oven-dry soil were weighed in duplicate into 500-cc. wide-mouth bottles. To each sample 30 mgm. of nitrogen as ammonium sulfate was added from standard solution. Distilled water was then added until the water content was 20 per cent. The total weight of each bottle was recorded, the bottle loosely stoppered with cotton, and then incubated at 28°C. At the end of 24 hours the bottles were removed from the incubator and the contents thoroughly stirred to insure equal distribution of moisture. They were then returned to the incubator and allowed to remain for 4 weeks. The moisture content was brought to weight each week, the contents being stirred the day after the addition of the water. At the end of the incubation period the bottles were removed from the incubator and distilled water added until the total water content was 400 cc. Each sample then received approximately 5 gm. of finely divided calcium oxide. The bottle was securely stoppered, and placed in the shaker for 10 minutes. After standing until flocculation was complete each sample was filtered through paper and 200 cc. of the clear filtrate transferred to an 800-cc. Kjeldahl flask. To each aliquot, 5 cc. of concentrated sodium hydroxide was then added and the contents boiled to half volume to remove the ammonia. The volume was then restored, Devarda's alloy powder added to reduce the nitrate, and the ammonia distilled into standard acid. Frequent tests were made to insure complete reduction of the nitrate and in no case was incomplete reduction noted.

The analyses for total water-soluble salts were made as described by Neidig and Magnuson (6).

RESULTS

The salts were added to the soil on July 11, 1921 and the first samples taken the following day. The analyses for salt content were made within the next 10 days and the nitrification tests begun 15 days after sampling. The second samples were taken after 9 months and 17 days, and the third samples after 14 months and 25 days. In order to have a series comparable with other data on the effects of alkali salts on nitrification, another series, known as the "initial series," was added. This series was obtained by weighing 100-gm. portions of the untreated soil into 500-cc. wide-mouth bottles and adding the alkali salts from standard solutions giving the concentrations found in the pots. From this point they were handled like the other nitrification tests. This initial series shows the effects of the salts on nitrification when added the day the nitrification tests began, while the first sampling from the pots is after 2 weeks' contact of salt and soil. This first sampling will hereafter be called the "first period," the second sampling, after 9 months and 17 days, will be called the second period, while the third sampling, after 14 months and 25 days, will be called the third period.

All the data presented in the tables and figures are taken from the results obtained from the cropped series of pots. Data obtained from the uncropped series and from a duplicate series seeded to alfalfa, none of which are shown here, are taken into consideration in making deductions and drawing conclusions. The results from these latter two series are so nearly the same as those obtained from the wheat series that it is not deemed advisable to occupy the space required to present them separately.

The salt-recovery data in the tables are expressed as total water-soluble salt at each period. It will be observed in the charts that in addition to the total salt these data are expressed in amounts of carbonate, chloride and sulfate. This will be of assistance in showing the amount of each salt recovered at each of the periods.

Single-salt treatments

The effects of the salts in single applications on the nitrification of ammonium sulfate at the various periods of the experiment, together with the recoverable salt at the same periods, are shown in table 1 and represented graphically in figure 1. The nitrification data are shown in percentages, the untreated control being considered as 100 per cent. The results of the salt analyses are expressed as grams of salt per 100 gm. of anhydrous soil.

It is apparent from the data in table 1 and figure 1 that sodium carbonate has stimulated nitrification in every case except the two highest concentrations in the initial period. The application of 0.6 per cent at this period reduces nitrate formation approximately 12 per cent while an application of 0.9 per cent almost inhibits nitrification. All concentrations are stimulating at the first period, slightly more stimulating at the second, and give the maximum

stimulation at the third period. The total salt recovery at the first period varies from 24.3 per cent to 39.8 per cent of the added salt. The recovery at the second period was slightly below the first, while the recovery at the third period was slightly greater than at the second. An application of 0.9 per cent was extremely toxic at the initial period but proved stimulating at the third period with a recovery of 0.320 per cent. A concentration of 0.317 per cent recoverable salt from this same pot at the second period gave a lower stimulation than the 0.320 per cent at the third period. This indicates that total recoverable salt within the limits of this experiment is not the factor determining stimulation or toxicity over any length of time. It will be observed from figure 1 that the recoverable salt in each case was practically all carbonate.

TABLE 1

Effects of alkali salts on nitrification in soil

Single-salt treatments

TREATMENT	INITIAL	FIRST SAMPLING		SECOND SAMPLING		THIRD SAMPLING	
	Nitrification	Nitrification	Salt recovery	Nitrification	Salt recovery	Nitrification	Salt recovery
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
None....................	100.0	100.0	0.054	100.0	0.031	100.0	0.046
Na₂CO₃ 0.2...............	110.0	115.9	0.101	119.5	0.094	126.0	0.111
Na₂CO₃ 0.4...............	101.0	120.5	0.178	114.0	0.141	129.5	0.169
Na₂CO₃ 0.6...............	88.4	119.0	0.237	127.4	0.195	122.5	0.210
Na₂CO₃ 0.9...............	15.2	119.0	0.392	138.1	0.317	162.0	0.320
NaCl 0.1...............	103.5	108.0	0.111	93.6	0.123	89.7	0.081
NaCl 0.2...............	77.0	90.5	0.177	93.2	0.214	93.4	0.131
NaCl 0.4...............	53.8	81.6	0.296	80.1	0.281	85.5	0.118
Na₂SO₄ 0.2...............	107.3	104.2	0.174	99.1	0.209	89.0	0.233
Na₂SO₄ 0.4...............	105.1	105.6	0.337	103.9	0.422	84.6	0.384
Na₂SO₄ 0.6...............	86.4	103.1	0.517	109.7	0.563	82.8	0.499
Na₂SO₄ 0.9...............	62.4	100.4	0.726	98.3	0.780	81.0	0.687

These results with the carbonate in the initial series are not in accord with the results obtained by Lipman or Greaves, but are similar to those obtained by Brown and Hitchcock. Lipman and Greaves each found carbonate toxic throughout the entire series of concentrations employed, while Brown and Hitchcock found a stimulation up to a concentration of 0.3 per cent, and higher amounts only slightly toxic. The initial series alone in this work is comparable to the work above cited.

Sodium chloride was toxic toward nitrate formation in practically every case. The toxicity from the 0.2- and 0.4- per cent applications is marked in the initial series but less apparent at the three later periods. At the final period a total salt recovery of 0.081 per cent is nearly as toxic as a recovery of 0.118 per cent. There seems to be no direct correlation between total salt

recovery and toxicity, except at the initial period.   It will be noted in figure 1
that not only does the total recoverable salt decrease with each period but
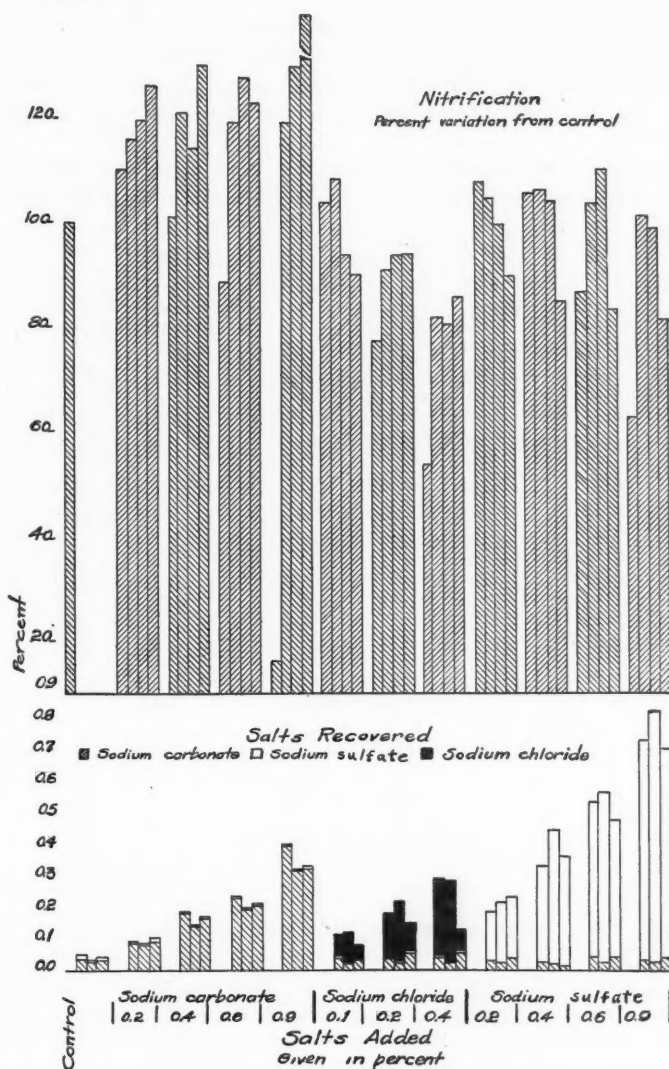
FIG. 1. SINGLE-SALT TREATMENTS

that the relative amount of the chloride decreases.   For example an application
of 0.4 per cent sodium chloride gives recovery of 0.296 total salt at the first
period, 0.254 per cent of this being the chloride.   At the second period the

total salt recovery is 0.281 per cent, of which 0.257 per cent is the chloride. At the final period the total salt recovery is 0.118 per cent, but only 0.064 per cent of this is the chloride. There is obviously a loss of the chloride salt as time progresses. This loss does not decrease the toxic action.

The toxicity of the chloride salt is not so marked as that reported by Lipman, Greaves and Carter, or Brown and Hitchcock, but their investigations generally were in sandy soil and based on salt additions rather than soluble-salt recovery.

The effect of the sulfate on nitrate formation is particularly interesting in that a more toxic action is noted at the third period than at the preceding

TABLE 2

Effects of alkali salts on nitrification in soil

Double-salt treatments

TREATMENT			INITIAL	FIRST SAMPLING		SECOND SAMPLING		THIRD SAMPLING	
Na_2CO_3	NaCl	Na_2SO_4	Nitrifi-cation	Nitrifi-cation	Salt recovery	Nitrifi-cation	Salt recovery	Nitrifi-cation	Salt recovery
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
...	....	...	100.0	100.0	0.054	100.0	0.031	100.0	0.046
0.1	0.10	...	109.7	111.0	0.154	107.2	0.128	105.6	0.100
0.3	0.05	...	111.0	119.3	0.187	114.0	0.164	129.5	0.146
0.1	0.30	...	88.3	103.5	0.327	100.5	0.256	109.2	0.147
0.6	0.10	...	84.9	122.5	0.327	126.7	0.292	116.2	0.252
0.2	0.20	...	96.2	111.7	0.211	111.0	0.184	121.5	0.150
...	0.05	0.2	91.5	103.5	0.268	100.8	0.222	91.5	0.190
...	0.30	0.1	66.2	92.6	0.392	90.8	0.326	92.5	0.221
...	0.10	0.4	74.5	102.5	0.393	90.8	0.405	87.2	0.404
...	0.10	0.6	56.8	87.3	0.631	100.5	0.527	86.4	0.554
0.1	....	0.1	113.8	116.9	0.148	115.2	0.172	115.0	0.130
0.2	....	0.2	107.2	117.5	0.243	123.4	0.234	119.0	0.228
0.3	....	0.4	108.5	111.6	0.461	121.2	0.299	127.8	0.338
0.2	....	0.6	104.9	67.6	0.555	89.0	0.570	100.4	0.555
0.6	....	0.1	98.0	113.4	0.324	128.9	0.279	123.4	0.269
1.0	....	0.1	18.6	113.0	0.445	156.0	0.426	58.1	0.412

periods. This toxicity at the third period was persistent in all pots. Concentrations of 0.2 per cent and 0.4 per cent were slightly stimulating in the initial series, while 0.6 per cent and 0.9 per cent were toxic. The results at the first period in all concentrations employed were approximately the same as the control, indicating neither toxicity nor stimulation. The same may be said for the second period. It is interesting to note that in every case the salt recovery at the second period is greater than at the first period. At the third period the salt recovery is less, but nitrification is not so good. At the third period all concentrations gave a decreased nitrate formation and all ranked about the same regardless of salt concentration. It is apparent from

the data that total sulfate recovery, within the limits of the experiment, is not the factor governing the toxicity or stimulation to the nitrifying bacteria. It will be observed in chart 1 that the sulfate recovered at each period is directly proportional to the added amount. In other words the percentage of sulfate in the total salt recovered remains approximately the same.

These results with the sulfate in the initial series are not in accord with those reported by Lipman, and Greaves et al. They found a toxicity from applications of sodium sulfate, all concentrations from small to large exhibiting this toxic action. Brown and Hitchcock found additions up to 0.2072 per cent stimulating to the nitrifying bacteria. The latter investigators apparently used a silt loam soil, although it is not stated, and employed ammonium sulfate as the nitrifiable substance while the former chose a sandy soil and employed blood for nitrification.

Double-salt treatments

The effect of two-salt combinations on the nitrification of ammonium sulfate in the soils is shown in table 2 and represented graphically in figure 2. The nitrification data are expressed in percentages, the control being considered as 100 per cent. The salt data are expressed in percentages of anhydrous soil.

Table 2 and figure 2 show that combinations of carbonate and chloride stimulate the nitrification of ammonium sulfate in all concentrations employed at the first, second and third periods. Only three combinations are toxic in the initial series, and this toxicity is slight. An apparent equilibrium is reached at the first period where nitrification progresses as rapidly as at the later periods. The amount of water-soluble salt gradually decreases with time and is materially lower at the third period than at the first. Total salt concentration in the combinations employed seems not to be a factor affecting the nitrifying organisms. These results are interesting in that they show a tendency of the carbonate to overcome the toxicity of the chloride as measured by nitrification. Sodium chloride in original applications from 0.1 to 0.4 per cent is toxic in practically every case at every period while the carbonate is stimulating throughout. We now find this stimulating action of the carbonate entirely masking the toxic action of the chloride since one salt is stimulating and the other toxic, the result of a combination of the two being the sum of a plus and minus quantity neither of which is strictly quantitative. It also will be observed in figure 2 that the relative percentage of chloride in the total salt decreases with each period. This loss was noted in the single application of the chloride but is not noted with the other salts.

Table 2 and figure 2 show that the chloride and sulfate, both toxic when applied alone, exhibit no antagonism toward each other as measured by nitrification. Let us take from table 1 the data resulting from the application of 0.6 per cent sodium sulfate and that resulting from the application of 0.1 per cent sodium chloride and compare with the data in table 2 resulting from the application of a combination of 0.6 per cent sulfate and 0.1 per cent chloride.

We then have the following:

TREATMENT	INITIAL	FIRST PERIOD	SECOND PERIOD	THIRD PERIOD
per cent	per cent	per cent	per cent	per cent
Sulfate, 0.6.................................	86.4	103.1	109.7	82.8
Chloride, 0.1................................	103.5	108.0	93.6	89.7
Sulfate, 0.6, and chloride, 0.1.................	56.8	87.3	100.5	86.4
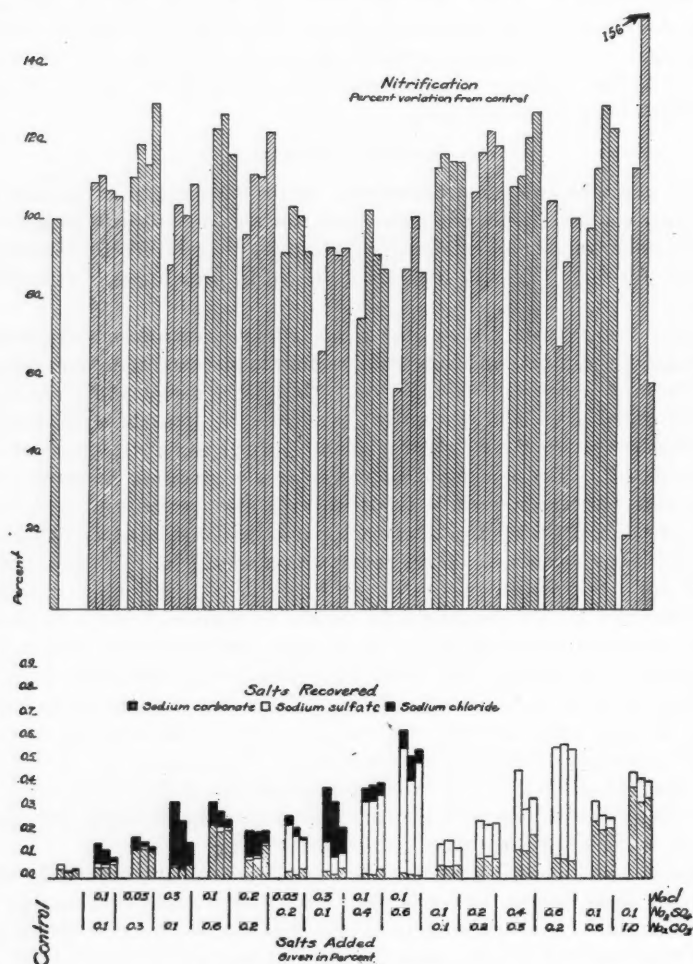
FIG. 2. DOUBLE-SALT TREATMENTS

It is apparent that neither salt has overcome the toxicity of the other, in fact the toxicity is increased. Let us take from table 1 the data resulting from the application of 0.4 per cent sulfate and that resulting from 0.1 per cent chloride and compare with the data in table 2 resulting from the combination of 0.4 per cent sulfate and 0.1 chloride. We then have the following:

TREATMENT	INITIAL	FIRST PERIOD	SECOND PERIOD	THIRD PERIOD
per cent	per cent	per cent	per cent	per cent
Sulfate, 0.4................................	105.1	105.6	103.9	84.6
Chloride, 0.1...............................	103.5	108.0	93.6	89.7
Sulfate, 0.4, and chloride, 0.1..................	74.5	102.5	90.8	87.2

The chloride is barely toxic alone at 0.1 per cent, the sulfate is toxic only at the third period, but the combination of the two has toxic action in the initial, second and third periods.

Table 2 shows that 0.1 per cent sodium sulfate does not affect the toxicity of 0.3 per cent sodium chloride. These results are not due to total salt concentration. A high nitrate formation may accompany either high or low total salt concentration and the toxicity does not decrease with each successive period.

Table 2 and figure 2 show also that carbonate and sulfate react in combination toward nitrification somewhat as one would expect from the results of treatments of each salt alone presented in table 1. The carbonate alone is stimulating to nitrification in all concentrations and at all periods except the initial when the two highest concentrations alone were toxic. The sulfate alone had practically no toxic action at the initial, first, and second periods but was slightly toxic at the third period. We now find that in combination the carbonate overcomes the slight toxicity of the sulfate. The data from table 1 resulting from the application of 0.2 per cent carbonate and that resulting from the application of 0.2 per cent sulfate compared with the data resulting from a combination of 0.2 per cent of each presented in table 2, give the following:

TREATMENT	INITIAL	FIRST PERIOD	SECOND PERIOD	THIRD PERIOD
per cent	per cent	per cent	per cent	per cent
Carbonate, 0.2..............................	110.0	115.9	119.5	126.0
Sulfate, 0.2.................................	107.0	104.2	99.1	89.0
Carbonate, 0.2, and sulfate, 0.2................	107.2	117.5	123.4	119.0

The favorable action of the carbonate has overcome the toxic action of the sulfate. It is apparent at a glance at table 1 that the sulfate applied alone is uniformly toxic at the third period. The data in table 2 show at a glance

that the carbonate has overcome this toxicity at the third period.   The low nitrate formation at the end of the column is due to the high carbonate.

The results of the total salt analyses show conclusively that the toxic or favorable action of these combinations toward nitrification is not proportionate to total salt recovery.

Triple-salt treatments

The effects of combinations of sodium carbonate, sodium chloride and sodium sulfate along with chemical analyses at the various periods, are shown in table 3 and represented graphically in figure 3.

TABLE 3

Effects of alkali salts on nitrification in soil

Triple-salt treatments

TREATMENT			INITIAL	FIRST SAMPLING		SECOND SAMPLING		THIRD SAMPLING	
Na_2CO_3	NaCl	Na_2SO_4	Nitrification	Nitrification	Salt recovery	Nitrification	Salt recovery	Nitrification	Salt recovery
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
....	....	....	100.0	100.0	0.054	100.0	0.031	100.0	0.046
0.05	0.05	0.05	104.9	102.1	0.168	93.6	0.084	92.5	0.088
0.10	0.10	0.10	104.1	95.1	0.292	103.9	0.228	90.7	0.166
0.20	0.10	0.10	108.2	111.6	0.308	116.5	0.226	120.8	0.232
0.40	0.05	0.10	104.1	113.0	0.355	117.9	0.331	128.6	0.236
0.60	0.10	0.20	82.5	108.5	0.532	134.4	0.500	135.6	0.475
0.40	0.10	0.40	105.1	111.5	0.629	125.9	0.520	128.6	0.401
0.20	0.05	0.40	106.9	107.0	0.555	121.2	0.790	111.9	0.468
0.20	0.05	0.80	70.4	90.1	0.990	105.9	0.750	104.9	0.676
0.05	0.05	0.60	92.4	78.9	0.795	68.2	0.535	87.6	0.583
0.10	0.05	0.10	18.6	109.1	0.297	117.4	0.175	106.5	0.187
0.40	0.10	0.60	70.4	104.2	0.612	131.3	0.673	129.4	0.731
0.30	0.20	0.20	82.7	111.6	0.417	124.1	0.432	109.2	0.509
0.10	0.20	0.20	77.9	106.0	0.358	112.3	0.368	102.3	0.347
0.10	0.40	0.10	50.3	91.9	0.404	113.1	0.354	133.0	0.264

The first impression gained from the data in the table and figure is the high percentage of treatments which result in increased nitrate formation.   Of the 54 separate figures representing nitrate formation 39 show stimulation and 17 show a toxic action.   Of the 17 toxic treatments 8 are in the initial series, 4 in the first period, 2 in the second period and 3 in the third period.   With the exception of one or two treatments in the initial series there is no outstanding toxicity.   In general the increased carbonate is accompanied by increased nitrate formation.   This is more apparent in figure 3.   The only case in which toxic action persists throughout the entire duration of the experiment is from an original application of 0.05 per cent chloride, 0.6 per

cent sulfate and 0.05 per cent carbonate. The toxicity in this case is greater than the toxicity resulting from the application of 0.6 per cent sulfate alone. The carbonate is too low to counteract the toxicity of the sulfate. The toxicity from this treatment is not due to total salt content, as shown by the data of

FIG. 3. TRIPLE-SALT TREATMENTS

the salt analyses. Table 2 and figure 2 show that combinations of sulfate and chloride, even in low concentrations, are persistently toxic at all periods. It requires considerable carbonate to overcome this action. A study of figure 3 will bring this out more clearly. We find original applications of
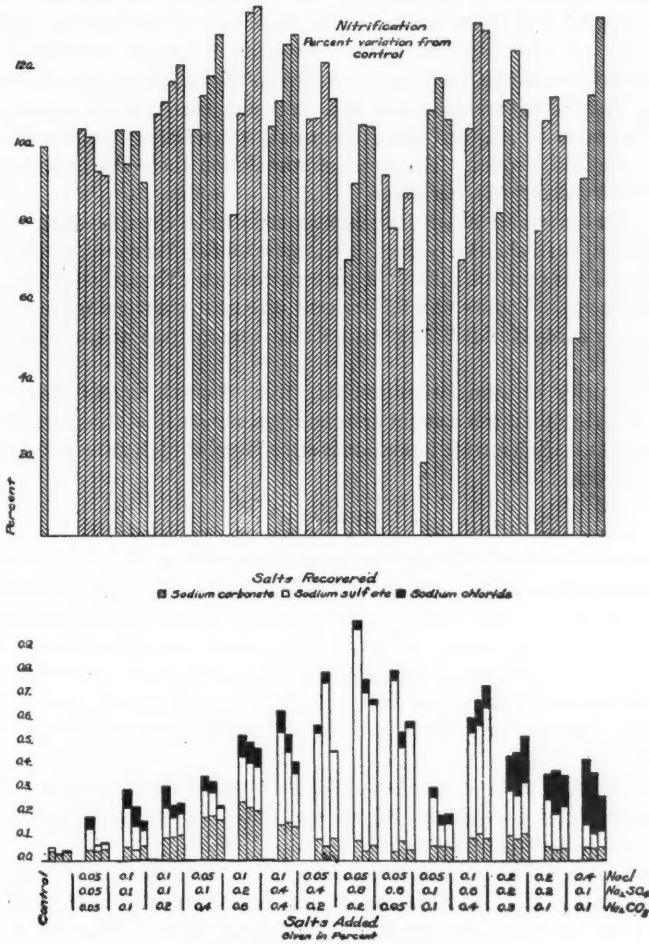
0.05 per cent chloride, 0.6 per cent sulfate, and 0.05 per cent carbonate quite toxic. Reading right to left from this point we find the sulfate increased to 0.8 per cent and the carbonate increased to 0.2 per cent and the toxicity decreased. In the next case the sulfate is reduced to 0.4 per cent while the carbonate remains at 0.2 per cent, and the result is stimulation at all periods. Continuing we find the carbonate increased to 0.4 per cent and the chloride increased to 0.1 per cent, the sulfate remaining at 0.4 per cent with a still more marked stimulation to nitrate formation. Finally the carbonate reaches 0.6 per cent and the stimulation is at a maximum, except at the initial series, which indicates that the carbonate concentration is reaching a toxic concentration in the initial series. The curve of stimulation then drops again as the carbonate concentration decreases.

The carbonate also has a tendency to counteract chloride when applied with sulfate, but a chloride increase is felt more quickly than a sulfate increase. Chloride 0.3 per cent and sulfate 0.1 per cent were toxic throughout the double-salt treatment. We now find 0.1 per cent carbonate overcoming the toxicity of a 0.4-per cent chloride 0.1-per cent sulfate combination at the second and third periods.

Any toxicity or stimulation resulting from the salt applications is not proportional to total salt content or osmotic pressure, within the limits of these experiments. High nitrate formation is often found at high salt concentration, and vice versa.

SUMMARY

A neutral silt loam soil was treated with various combinations of sodium carbonate, sodium sulfate and sodium chloride, and the effects of these salts singly and in two- and three-salt combinations were determined on nitrate formation from ammonium sulfate. These effects were determined immediately after the addition of the salts, at the end of 15 days, again at the end of 9 months and 17 days, and finally at the end of 14 months and 25 days. Chemical analyses for water-soluble salts were made at each of the three periods.

A sodium carbonate application of 0.2 per cent had the immediate effect of stimulating nitrate formation, 0.4 per cent had no effect, while applications of 0.6 and 0.9 per cent were toxic.

Applications of carbonate from 0.2 to 0.9 per cent gave a water-soluble concentration of 0.101 to 0.392 per cent at the first period, 0.094 to 0.317 per cent at the second period, and 0.111 to 0.320 per cent at the third period. All concentrations stimulated nitrate formation at the first, second and third periods.

Sodium chloride was found slightly toxic throughout from original applications of 0.1 per cent, 0.2 per cent and 0.4 per cent, except in the lowest concentration. These applications resulted in water-soluble concentrations of 0.111 to 0.296 per cent at the first period, 0.123 to 0.281 per cent at the second

period, and 0.081 to 0.118 per cent at the third period. The toxicity remained throughout the four periods of the experiment regardless of the gradually decreasing water-soluble chloride. The percentage of chloride in the total water-soluble salt decreased materially at the last period.

Sodium sulfate in applications from 0.2 per cent to 0.4 per cent slightly stimulated nitrate formation at the initial period while applications of 0.6 and 0.9 per cent retarded it. These applications resulted in concentrations of water-soluble salt from 0.174 to 0.726 per cent at the first period, 0.209 to 0.780 per cent at the second period, and 0.233 to 0.687 per cent at the third period. The toxicity disappeared at the first and second periods but returned at the third in all concentrations.

Sodium carbonate counteracted the toxicity of sodium chloride at the first, second, and third periods, and in some cases at the initial period.

Chloride and sulfate were in general slightly toxic when applied in combination.

Carbonate and sulfate in general gave a stimulation, the stimulating action of the carbonate counteracting any toxic action of the sulfate.

Combinations of the three salts together were in general stimulating. This was particularly true where the concentration of carbonate was not materially below that of the sulfate or chloride. Very low carbonate in combination with high sulfate and chloride resulted in a toxic action.

There was a general tendency for any toxic action resulting from applications of salts, either singly or in combinations of two or three, to disappear as time progressed. Sulfate applied alone was an exception.

Chemical analyses at the stated periods showed conclusively that any toxic or stimulating action was not proportional to total salt recovery within the limits of these experiments.

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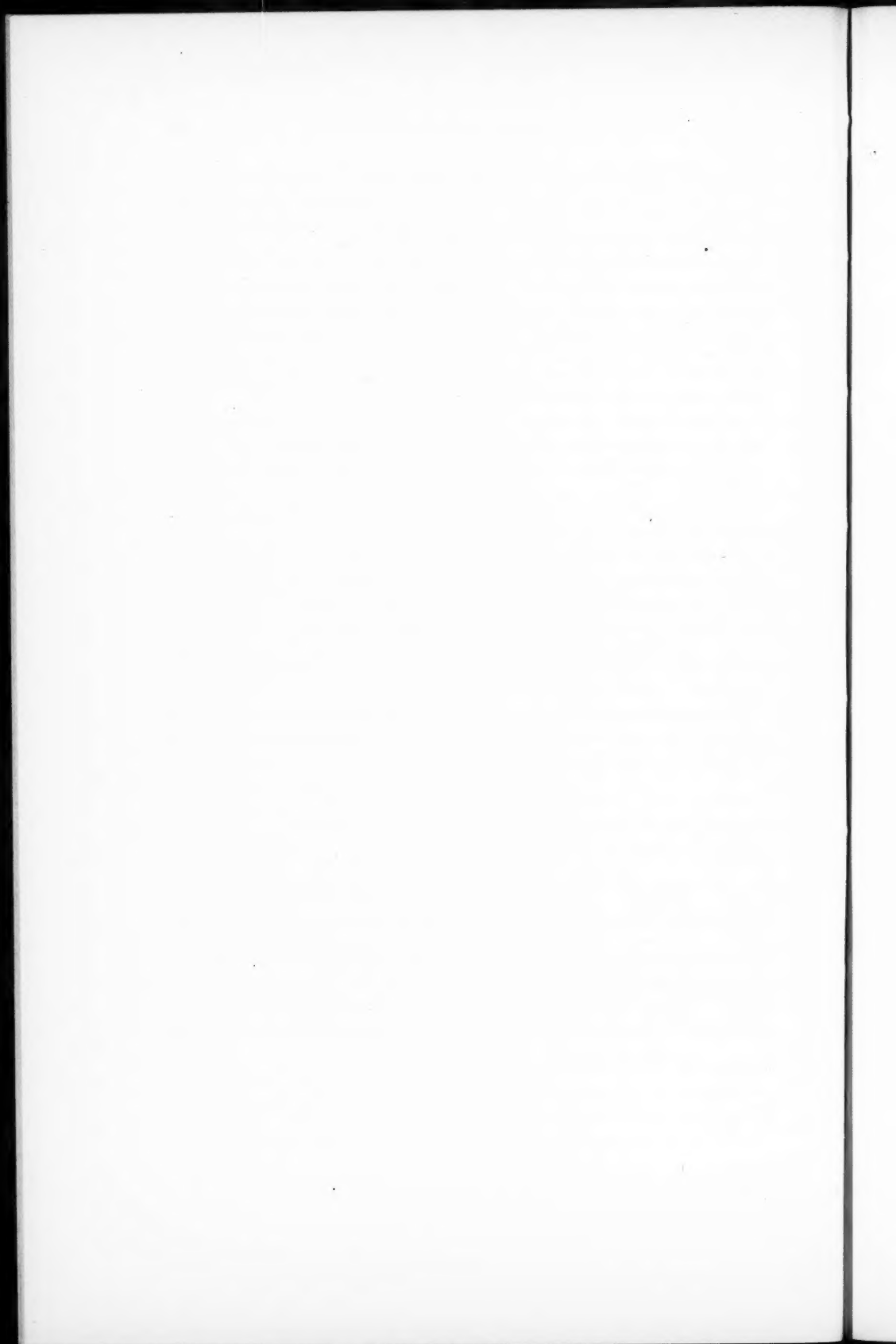
THE EFFECTS OF ALKALI SALTS ON BACTERIOLOGICAL ACTIVITIES IN SOIL: III. AMMONIFICATION, NITRIFICATION AND CROP YIELD[1]

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Detailed experiments to determine the effect of alkali salts on ammonification, nitrification and crop yield have been outlined in parts I and II.

RESULTS

In this paper a comparison of the effects of the salts on ammonification, nitrification, and crop yield is made, with no attempt to go into results of ammonification and nitrification in detail.

In order to compare the effects of the salts on ammonification and nitrification on the one hand, and crop yield on the other, it is necessary to take the average effects on the bacteriological processes at two succeeding periods. For example, the effects of the salts on ammonification and nitrification at the 15-day period, before the crop was planted, could not be compared with the effects on the crop harvested at a much later period. It also would be unfair to compare the effects on ammonification and nitrification at the second period, after the crop was harvested, with the yield of the crop just removed. In order to have a more accurate basis for comparison, the effects of the salts on ammonification and nitrification at the 15-day period were averaged with the same effects at the second period, immediately after the first crop was removed. This would give in a way the average effect on these processes during the time the first crop was actually growing. Likewise, the effects of the salts on the bacteriological processes after removal of the first crop is averaged with the effects after removal of the second crop. This gives in a way the average effect on these processes during the growing period of the second crop. In a similar manner to obtain the average water-soluble salt content over the growing period of the first crop, the total salt recovery at the 15-day period has been averaged with the salt recovery after the removal of the first crop. The salt analyses at the second and third periods have been averaged to determine the salt content during the growing period of the second crop.

371

The results of these averages and crop yields are shown in tables 1, 2 and 3. The effects on ammonification and nitrification, together with the salt analyses and crop yields at the various periods are shown in figures 1, 2 and 3. The data in the figures are not the average as above described, but are the actual data obtained at the various periods. The ammonification data are for the initial, first, second and third periods. In order to obtain the averages for the ammonification it was necessary to use the initial series instead of the 15-day period, but the difference at the two periods was so small that it does not materially affect the results.

Single-salt treatments

Table 1 and figure 1 show that the average carbonate recovery through the time the first crop was growing is approximately one-half to one-third the

TABLE 1

Effects of alkali salts on ammonification, nitrification and crop yield

Single-salt treatments

TREATMENT		FIRST PERIOD AND FIRST CROP				SECOND PERIOD AND SECOND CROP			
		Total Salt	Ammoni-fication	Nitri-fication	Crop yield	Total Salt	Ammoni-fication	Nitri-fication	Crop yield
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
None.................		0.041	100.0	100.0	100.0	0.039	100.0	100.0	100.0
Na₂CO₃	0.2.........	0.097	99.5	117.7	70.7	0.102	111.6	122.7	121.0
	0.4.........	0.109	106.7	117.2	90.9	0.155	114.4	121.7	192.8
	0.6.........	0.216	99.0	118.2	59.6	0.202	120.9	124.9	31.4
	0.9.........	0.354	108.9	128.5	0.0	0.319	125.5	150.0	0.0
NaCl	0.1.........	0.117	71.7	105.8	108.5	0.102	92.8	91.6	87.0
	0.2.........	0.195	55.7	91.8	103.0	0.172	87.0	93.1	101.0
	0.4.........	0.288	51.7	80.8	79.4	0.199	88.2	82.8	139.2
Na₂SO₄	0.2.........	0.191	69.0	101.6	101.6	0.221	97.4	94.0	95.1
	0.4.........	0.379	71.6	104.7	106.3	0.403	97.1	94.2	142 8
	0.6.........	0.535	65.4	106.4	112.7	0.531	94.7	96.2	119.6
	0.9.........	0.753	56.0	99.3	91.1	0.733	84.4	89.6	162.5

amount added.   More than half the chloride is recovered at the same period, and approximately 80 per cent of the sulfate. In the following discussion the percentage of recoverable salts in the water extract rather than the added amount will be taken.

The applications of carbonate have little effect on ammonification at the first period. The results are not regular but in general show no toxicity but a slight indication of stimulation. The effect on nitrification is obviously one of stimulation, this effect reaching a maximum at 0.354 per cent, the highest salt concentration in the series. All applications proved toxic to the

first crop, 0.354 per cent entirely preventing growth and 0.216 per cent reducing it nearly one-half.   Thus we see applications of the carbonate, which
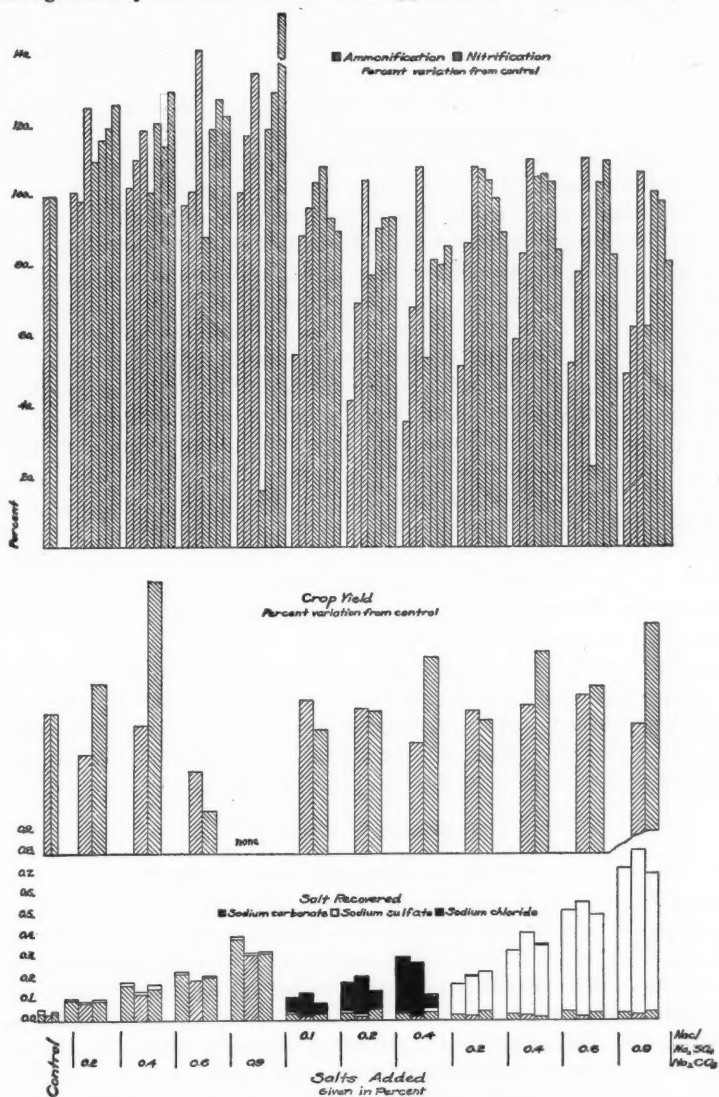

FIG. 1. SINGLE-SALT TREATMENTS

slightly stimulate the ammonifying organisms and markedly stimulate the nitrifying bacteria, proving extremely toxic to the wheat plant.

At the second period of the experiment we find all concentrations of the

carbonate stimulating both to the ammonifying and nitrifying organisms. This stimulation is a little more marked in the case of nitrification than of ammonification. The two lowest concentrations stimulate the yield of the second crop. A concentration of 0.102 per cent increased the yield 21 per cent, while a concentration of 0.155 per cent increased it 92.8 per cent, but a concentration of 0.202 per cent reduced it to 31.4 per cent and a concentration of 0.319 per cent entirely prevented growth. Here, as in the preceding crop, we find concentrations of carbonate which retard or completely inhibit plant growth stimulating ammonification and nitrification.

In the chloride series at the first crop period, concentrations from 0.117 per cent to 0.288 per cent were decidedly toxic toward ammonification but had slight toxic action toward nitrification, and only in one case were toxic toward the growth of wheat. A concentration of 0.288 per cent retarded bacterial activities as well as crop growth. At the second period the toxicity toward ammonification and nitrification is approximately the same and there is no toxicity to the crop. A concentration of 0.199 per cent resulted in an increased crop yield. With the chloride then, we find the reverse condition of that with the carbonate, that is, concentrations which exert toxic action to ammonification and nitrification do not decrease the yield of wheat.

The sulfate in concentrations from 0.191 per cent to 0.753 per cent proved decidedly toxic toward ammonification at the first crop period, but had practically no effect on nitrification, and little or no effect on the growth of wheat. At the second crop period concentrations from 0.221 per cent to 0.733 per cent showed a slightly toxic effect toward ammonification and nitrification, but greatly stimulated plant growth.

Summarising the single-salt treatments, we find concentrations of sodium carbonate which retard and entirely inhibit the growth of wheat, exerting a stimulating action toward ammonification and nitrification, while concentrations of chloride and sulfate which retard ammonification and nitrification stimulate or have little or no effect on plant growth.

Double-salt treatments

In the carbonate-chloride combinations (table 2, fig. 2), at the first crop period we find all combinations quite toxic toward ammonification and generally stimulating nitrification. These same combinations all decrease the yield of wheat. The maximum toxicity to ammonification is associated with maximum chloride, while the maximum toxicity to the plant is found at the high carbonate treatment. The maximum stimulation to nitrification also is associated with high carbonate. Apparently the chloride has not decreased the toxicity of the carbonate to plant growth at this first period. At the second crop period the toxicity toward ammonification has largely disappeared, nitrification is stimulated, and the crop yield is greatly increased. The salt recovery is slightly below that of the first period, but the decreased toxicity at the second period is not pro-

portional to total recoverable water-soluble salt. The increased yield may be due partly to the increased bacterial activities which give an accumulation of food for the second crop. The application of 0.6 per cent carbonate and 0.1 per cent chloride gave a crop yield of 215 per cent at the second period, while the 0.6 per cent application of carbonate gave a yield of only 31.4 per cent at the same period when applied alone. This indicates that the chloride has been instrumental in decreasing the carbonate toxicity at the second period. It also is interesting to note that 0.172 per cent chloride gave a crop yield of 101 per cent at the second period, while an original

TABLE 2

Effects of alkali salts on ammonification, nitrification, and crop yield

Double-salt treatments

TREATMENT			FIRST PERIOD AND FIRST CROP				SECOND PERIOD AND SECOND CROP			
Na_2CO_3	NaCl	Na_2SO_4	Total salt	Ammoni-fication	Nitri-fication	Crop yield	Total salt	Ammoni-fication	Nitri-fication	Crop yield
per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
0	0	0	0.041	100.0	100.0	100.0	0.039	100.0	100.0	100.0
0.1	0.10	0	0.141	71.2	109.1	95.4	0.114	94.8	106.4	124.8
0.3	0.05	0	0.175	86.8	116.6	97.3	0.155	105.0	121.7	150.9
0.1	0.30	0	0.291	55.4	102.0	64.0	0.201	86.3	104.8	185.3
0.6	0.10	0	0.309	81.7	124.8	56.5	0.272	109.4	121.4	215.1
0.2	0.20	0	0.197	71.3	111.3	97.3	0.167	95.9	116.2	173.8
0	0.05	0.2	0.245	65.2	102.1	98.0	0.206	91.0	96.1	113.1
0	0.30	0.1	0.359	63.4	91.7	72.1	0.273	82.2	91.6	189.6
0	0.10	0.4	0.399	69.8	96.6	60.5	0.404	86.5	89.0	180.9
0	0.10	0.6	0.579	65.5	93.9	50.4	0.540	83.8	93.4	233.2
0.1	0	0.1	0.160	81.3	116.0	98 2	0.151	98.3	115.1	107.6
0.2	0	0.2	0.238	83.0	120.4	99.4	0.231	100.0	121.2	143.3
0.3	0	0.4	0.380	83.0	116.4	101.1	0.318	91.4	124.5	201.5
0.2	0	0.6	0.562	72.7	78.3	112.2	0.562	84.7	94.7	161.3
0.6	0	0.1	0.301	93.6	121.1	64.2	0.274	108.1	126.1	147.2
1.0	0	0.1	0.435	9.62	134.5	0	0.419	114.9	107.0	0

application of 0.3 per cent chloride and 0.1 per cent carbonate together, resulting in a total recoverable salt concentration of 0.201 per cent at the second period, gave a crop yield of 185 per cent. This indicates an antagonism as measured by crop yield in the second period.

In the sulfate-chloride series at the first crop period all concentrations are decidedly toxic to ammonia formation, have little or no effect on nitrate formation, and are decidedly toxic to the growth of wheat. Both sulfate and chloride exerted a toxic action toward ammonia formation when applied alone, but a lesser toxic action toward nitrate formation, and toxicity to plant growth only in the highest concentration. In combination, even in a

relatively low total salt concentration, a marked toxic action is noted toward ammonification and crop yield. At the second period the combinations still remain slightly toxic toward ammonification and nitrification, but stimulate the growth of wheat. The salt recovery is slightly less than at the first
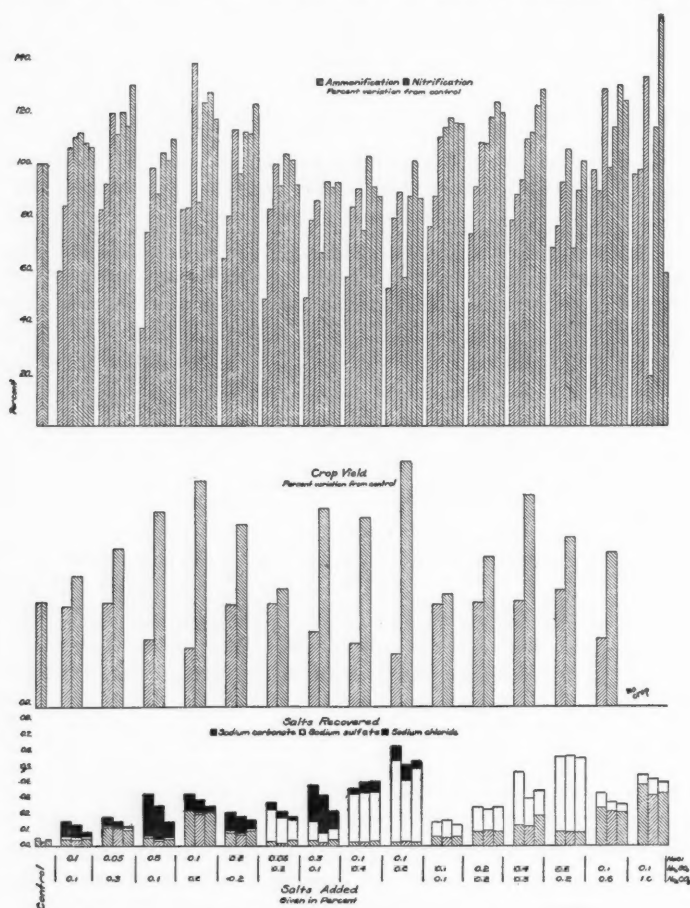
FIG. 2. DOUBLE-SALT TREATMENTS

period, but the increased plant growth at the second period is not proportional to the total recoverable water-soluble salt.

It will be observed in table 1 that an original application of 0.1 per cent chloride did not reduce the first crop, and 0.6 per cent sulfate actually increased the yield. In table 2 we note that a combination of 0.1 per cent chloride and 0.6 per cent sulfate reduced the first crop yield about one-half.

This does not indicate any antagonism on the part of the two salts as measured by crop yield. This difference in yield is not accounted for by the total recoverable salt, as the amount in the two cases is approximately the same. The continued toxicity to ammonification and nitrification of the combinations of chloride and sulfate at the second period is noteworthy. Thus we find combinations of the two salts which remain toxic toward the two bacteriological processes materially increasing the crop yield.

In the carbonate-sulfate series at the first period all combinations proved slightly toxic toward ammonia formation, and all but one stimulated nitrate formation. Two of the combinations were outstandingly toxic to the plant

TABLE 3

Effects of alkali salts on ammonification, nitrification, and crop yield

Triple-salt treatments

TREATMENT			FIRST PERIOD AND FIRST CROP				SECOND PERIOD AND SECOND CROP			
Na₂CO₃	NaCl	Na₂SO₄	Total salt	Ammoni-fication	Nitri-fication	Crop yield	Total salt	Ammoni-fication	Nitri-fication	Crop yield
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
0	0	0	0.041	100.0	100.0	100.0	0.039	100.0	100.0	100.0
0.05	0.05	0.05	0.126	89.9	97.8	105.9	0.086	107.4	93.0	132.1
0.10	0.10	0.10	0.260	87.5	99.5	107.8	0.197	101.4	97.3	109.1
0.20	0.10	0.10	0.263	82.9	114.0	113.8	0.229	98.6	118.6	140.6
0.40	0.05	0.10	0.343	91.3	115.4	124.5	0.283	103.2	123.2	151.0
0.60	0.10	0.20	0.516	80.8	121.4	29.5	0.487	90.4	135.0	108.7
0.40	0.10	0.40	0.574	82.5	118.7	73.9	0.460	88.5	127.2	187.2
0.20	0.05	0.40	0.672	82.7	114.1	103.8	0.629	90.2	116.0	216.3
0.20	0.05	0.80	0.870	79.7	98.0	46.0	0.713	87.1	105.4	182.2
0.05	0.05	0.60	0.665	78.3	73.5	98.1	0.559	89.3	77.9	201.5
0.10	0.05	0.10	0.236	84.9	113.2	90.5	0.181	93.3	111.9	123.2
0.40	0.10	0.60	0.642	60.5	117.7	58.6	0.702	80.8	130.3	156.0
0.30	0.20	0.20	0.424	71.7	117.8	56.7	0.470	68.6	116.6	146.4
0.10	0.20	0.20	0.363	73.7	109.1	59.8	0.357	75.2	107.3	176.5
0.10	0.40	0.10	0.379	66.1	102.5	18.0	0.309	80.1	123.0	161.1

and one combination was stimulating. The highest carbonate concentration inhibited plant growth, and the next highest greatly reduced the yield. These combinations stimulated nitrate formation and had little effect on ammonia formation. At the second period all combinations except one stimulated crop growth, in general stimulated nitrate formation, and had little effect on ammonia formation. From these carbonate-sulfate combinations we find in general a more detrimental action on ammonification than on nitrification or plant growth.

Triple-salt treatments

At the first period all 14 three-salt combinations were toxic toward ammonification (table 3, fig. 3), one proved toxic to nitrification, the remainder stimulated or had no effect, while 6 proved decidedly toxic

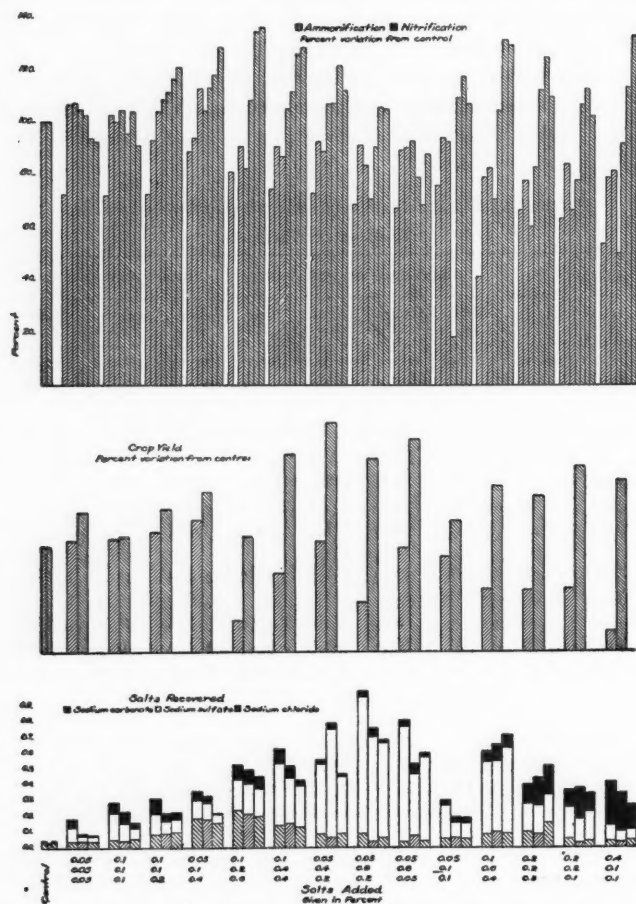FIG. 3. TRIPLE-SALT TREATMENTS

to plant growth and 5 increased the yield. The greatest toxicity to plant growth resulted from an original application of 0.1 per cent carbonate, 0.4 per cent chloride and 0.1 per cent sulfate. Why this combination should prove so toxic is not understood, since none of the three-salt additions approached the maximum tolerance concentration. The total salt concentra-

tion at this point is only 0.379 per cent. At the second period the results are quite different from those at the first. All combinations stimulated plant growth, not slightly but markedly in practically every case. Nitrification was stimulated in all but three combinations while ammonification generally decreased. It is apparent from the data that ammonification, nitrification and crop yield are not proportional to the total water-soluble salt recovery.

SUMMARY

A neutral silt loam soil was treated with various amounts and combinations of sodium carbonate, sodium chloride, and sodium sulfate to determine the effects on ammonia formation from blood, nitrate formation from ammonium sulfate, and the growth and yield of wheat. Samples of the treated soils were taken at regular intervals to determine the bacterial activities and total water-soluble salts. The results are presented in two periods, one representing the period the first crop was growing, and the second, the period of growth of the second crop.

There is a gradual decrease in total water-soluble salt as time progresses after application of the salts.

Sodium carbonate stimulated the ammonification of blood and nitrification of ammonium sulfate but was decidedly toxic to plant growth at the first period. At the second period both ammonification and nitrification were stimulated at all concentrations employed, while the crop yield showed stimulation at the two lowest concentrations only. No crop could be obtained at a concentration of 0.319 per cent of recoverable water-soluble salt, while at 0.202 per cent the yield was greatly reduced.

Sodium chloride at the first period was toxic toward ammonification and slightly toxic toward nitrification. Only the highest concentration employed, 0.288 per cent, was toxic to plant growth. At the second period the salt was slightly toxic to ammonification and nitrification but stimulated plant growth.

Sodium sulfate at the first period was toxic toward ammonification but had little or no effect toward nitrification or crop yield. At the second period it was slightly toxic to ammonification and nitrification but stimulated plant growth.

In the two-salt combinations at the first period there was toxicity toward ammonification in every case and toxicity to plant growth in all cases except two. There is in general a stimulation of nitrification. At the second period the toxicity to ammonification has decreased, nitrification in general is increased, and the crop is greatly stimulated.

In three-salt combinations at the first period all resulted in reduced ammonia formation, 6 combinations obviously decreased crop yield, and the majority increased nitrification. At the second period ammonia formation was still decreased while nitrification was increased and crop yield was greatly stimulated.
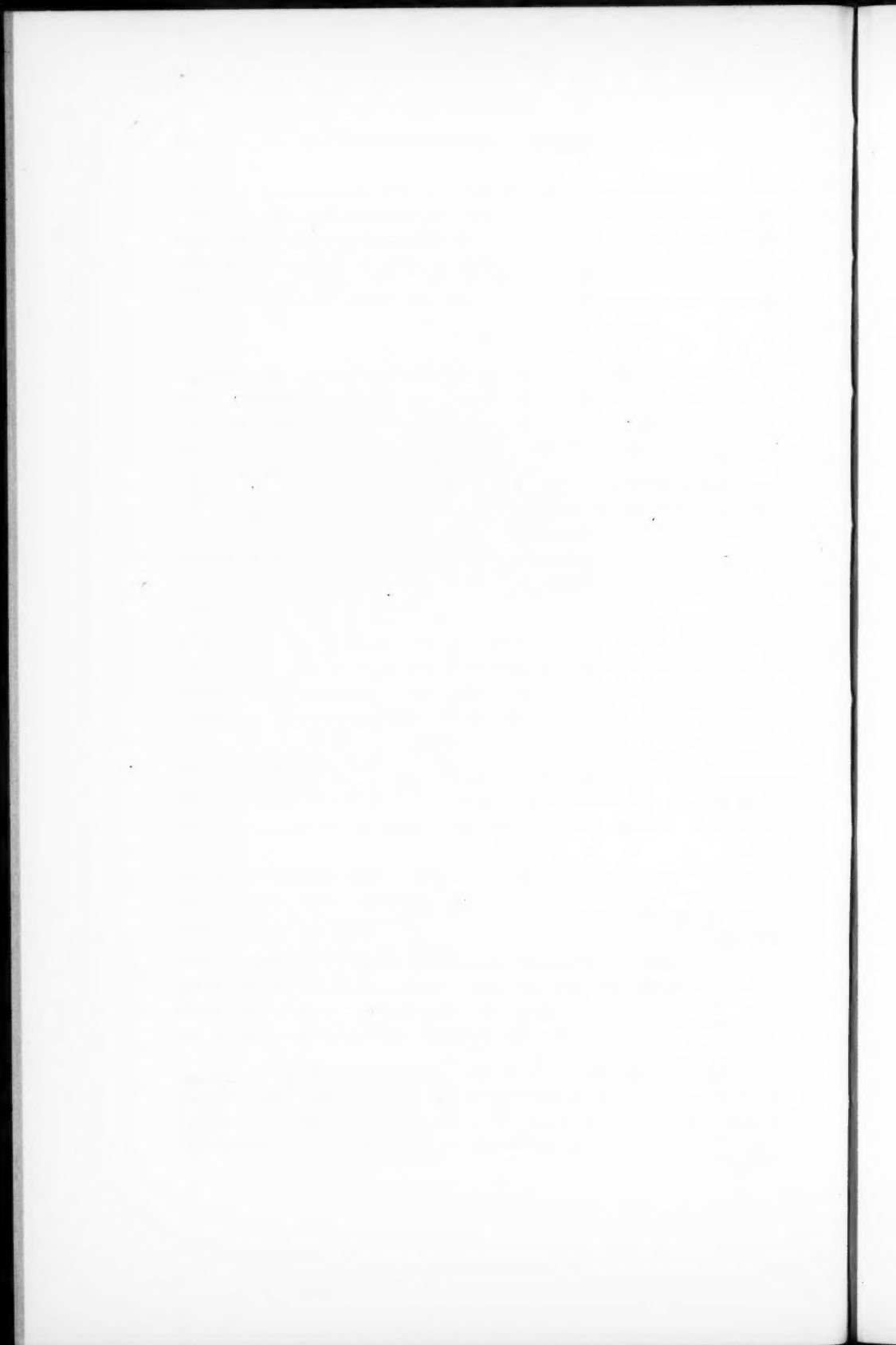
THE TEMPERATURE AND MOISTURE FACTORS IN NITRATE PRODUCTION[1]

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In tillage experiments at many experiment stations, sampling at intervals for nitrates is considered to be an important part of field plat routine. In the experiments at the Nebraska station it is beginning to appear that the importance of the nitrate factor in crop production cannot be demonstrated adequately by means of systematic sampling at empirical intervals. The many factors which determine nitrate elaboration do not seem to work the same each season and on different soils. On rich soils where nitrates accumulate rapidly at low temperatures and moisture contents, various tillage methods do not give results in agreement with those obtained on poor soils. Consequently investigations have been begu1 on the soils from both the Lincoln and North Platte experimental fields to supplement the tillage plat studies being carried on at these stations and to shed light on the nature of nitrate production under the influence of the various factors that occur in the field. This paper discusses the effect of variations in temperature and moisture on nitrate production.

While this paper deals with the performance of two soils in which experimentalists in this state are directly interested, certain broad applications to all soils are possible. The data presented may further serve to emphasize that experiments in several localities designed to develop and demonstrate the function of tillage may lead to quite different conclusions if the soils on which the experiments are conducted differ in nitrate performance for any reasons.

HISTORICAL[2]

Effects of temperature on nitrate production

It is commonly stated in text books on soils and agricultural bacteriology

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[1] Published with the approval of the Director as Paper No. 4, Journal Series, Nebraska Agricultural Experiment Station, Lincoln, Nebraska.

[2] After this manuscript was prepared for publication there came to our attention the recent article by Elias H. Panganiban, on "Temperature as a factor in nitrogen changes in the soil," in Jour. Amer. Soc. Agron., v. 17, no. 1, p. 1–32. This author has made a more extended review of the literature than is presented here. He determined the nitrate nitrogen produced in a 3-week period at 60 per cent of the water-holding capacity, under constant temperatures ranging by 5° intervals from 15° to 40°C., and also the nitrate

381

that nitrification is most active at temperatures around 35°C. (95°F.), decreases rapidly as the temperature rises or falls and is insignificant or stopped altogether at a temperature as high as 55° (131°F.) or as low as 5° (41°F.). This general statement is probably based on the work of Schloesing and Müntz, in 1879, who were the first to make a thorough study and interpretation of the phenomena of nitrification. In a short paper lacking entirely in details, they state (5):

Below a temperature of 5° nitrification is excessively slow, if not completely lacking; it becomes appreciable at about 12°. On continuing to elevate the temperature one finds that the quantities of nitrates increase rapidly. At 37° one reaches a maximum of activity; the formation of nitrates is very abundant at this temperature and at this temperature one may study in a few days phenomena which ordinarily demand months or even years for solution. Above 37° there is a rapid diminution; at 45° less nitrates are formed than at 15°. At 50° one obtains very small quantities. Around 55° there is not even a trace. Other things being equal, one may observe working under appropriate conditions, ten times as much nitrates at 37° as at 14°. The temperature is, therefore, a factor of great importance in the production of nitrates.

Warington (7) quoting Schloesing and Müntz, states that:

The series of temperature observations by Schloesing and Müntz has not, so far as I know, been confirmed by other investigators. . . . . Experience at Rothamsted shows that nitrification takes place pretty freely in the soil during an ordinary English winter. In one series of laboratory experiments, a considerable rate of nitrification was observed in solutions, the mean temperature of which was between 3° and 4°C. At summer temperatures, however, nitrification becomes far more rapid. . . . . At Rothamstead I failed to start nitrification in a solution maintained at 40°C.

King and Whitson (3), report work done in their laboratory by J. O. Belz, in which the rate of nitrate development was studied at temperatures near 35°, 50°, 70°, and 90°F. Clay loam soil from one of the Wisconsin station plots was used. Their data generally confirmed the observations of Schloesing and Müntz, however they found an appreciable nitrate accumulation at 35°F., amounting to 4.3 p.p.m. nitric nitrogen in a 4-week period.

Traaen (6) in a study of the effect of moisture on nitrification, incubated loam soil containing 0.2 per cent of ammonium sulfate at 13° and 25°C. At both temperatures nitrate production increased with the moisture content up to 17.5 per cent and then decreased with further increase in moisture content. Considerably more nitrates were developed at the higher temperature than at the lower in a 26-day period, but at the end of 66 and 100 days the lower temperature had been as effective as the higher, except at low moisture contents.

nitrogen produced under variable temperature conditions. He found that nitrification was optimum at 35°C., but differed widely in quantity of production for three soil types. In our paper are presented data confirming his conclusions, but covering a wider range of temperatures.

Effect of moisture on nitrate production

It is generally known that nitrification is at a maximum at a certain degree of wetness, and decreases with either more or less moisture. Greaves and Carter (2) have made a careful review of the literature on the effect of moisture on nitrification. Much of the literature is confusing and apparently conflicting, for investigators generally have failed to record any physical constants on the soils studied, by means of which the relative wetness of different soils can be compared.

Greaves and Carter (2) have studied the nitrifying power of 22 Utah soils ranging in texture from sand to tight clay, with Hilgard maximum water capacities ranging from 31 to 78 per cent, and moisture equivalents ranging from 3.32 to 45.15 per cent. They used 100 gm. of soil mixed with 2 gm. of blood meal in sterilized glass tumblers covered with Petri dishes. Incubations were made at 28°–30°C. for 21 days, and nitrates were determined by reduction to ammonia. The moisture conditions studied varied by 10 per cent intervals of the maximum water capacity up to 80 per cent. About half the samples studied produced maximum quantities of nitric nitrogen at 50 per cent saturation and the others produced most at 60 per cent. The average relative production of nitrates at different degrees of wetness they found to be as follows:

	RELATIVE SATURATION							
	10 per cent	20 per cent	30 per cent	40 per cent	50 per cent	60 per cent	70 per cent	80 per cent
Relative nitrate production.....	11.0	16.9	30.7	61.9	85.9	100	36.6	9.6

That a decrease in nitrate production would occur above a certain wetness is to be expected, for as Schloesing and Müntz explained (5), the closing of the pore spaces by water would reduce aeration which is an essential factor in nitrate production.

<div align="center">EXPERIMENTAL</div>

Plan of the experiments

Moisture and temperature are almost impossible of control in the field, and other factors affecting nitrification cannot be isolated or kept constant, consequently any exact work on the importance of moisture or temperature must be done in the laboratory. In laboratory studies on nitrification or other bacterial phenomena, the matter of the disturbance of field conditions must be given serious consideration. The season when the soil is taken, the crop growing upon the land, the initial nitrate content of the soil, the degree of drying and the amount of mixing given to the sample, the matter of aeration, temperature control, moisture control, and time of incubation allowed, all are factors that will enter into results obtained in the laboratory.

In this study the attempt has been made to simulate field conditions in the incubator as closely as possible. Soil from the surface 6 inches from fields of growing crops or stubble where nitrates were at a minimum, was dried only as much as was necessary, mixed thoroughly and used as soon as possible. A large mass of soil, 1000 gm., was incubated in 2-quart jars. The soil was compacted to field condition, and aeration comparable with field conditions was provided. Moisture content was controlled by frequent additions of distilled water. Temperature was controlled by thermoregulators.

In the temperature study, incubations were planned to run at 5°, 15°, 35°, 45°, and 55° on soil wet to the moisture equivalent. For both the Lincoln and the North Platte soils, the moisture equivalent is identical with the field carrying capacity, and the optimum water content. In the moisture study, incubations were planned to run at 25° on soil wet to the hydroscopic coefficient, one and one-half, and two times the hygroscopic coefficient, the moisture equivalent, and one and one-fourth times the moisture equivalent. Slight departures from this plan were necessary and will be obvious in the presentation of the data. Enough jars for each condition of temperature and moisture were provided to allow determination of nitrates at intervals of 1, 2, 3, and 4 weeks in the case of Lincoln soil and 1, 2, 3, 4, 6, and 8 weeks in the case of North Platte soil. Certain conditions of moisture and temperature not expected to show much change were not run longer than 4 weeks.

The soils used

The soil at Agronomy Farm at Lincoln is Carrington clay loam. This is a common soil type in southeastern Nebraska, originating from Kansas Drift and is peculiar among glacial soils for its scarcity of stones and gravel. The soil at the North Platte substation where the tillage experiments are located is Colby very fine sandy loam. This is a loessial type occurring extensively over southwestern Nebraska ar.d western Kansas. The Lincoln soil has been under cultivation for over 50 years, has been reasonably well managed, and generally raises good crops. The North Platte soil has been under cultivation for 40 years and is inherently very productive.

The physical character of the soils used in these studies is shown in table 1. The chemical character with respect to features affecting nitrification is shown in table 2.

The studies on the Lincoln soil were made in the summer of 1922. The soil used was taken from a field of growing wheat in June when nitrates were low in quantity. It was sifted through a ½-inch screen, roots being discarded, and spread in a thin layer on a cement floor in a dark room to dry for 2 days. It was then thoroughly mixed and used at once. The studies on the North Platte soil were made in December, 1923. The soil was taken from a wheat stubble field in November before freezing had occurred and shipped the same day to Lincoln.

The technique of incubation

A bulk of soil was moistened with the calculated amount of water required to bring it to the desired wetness, and mixed thoroughly.   A weight of wet soil equivalent to 1000 gm. of water-free soil was transferred to a 2-quart Mason jar and compacted with a spatula blade, or by jarring to a definite volume.   In the case of Lincoln soil, this volume was 1000 cc., giving a volume weight of 62.4 pounds per cubic foot, which experience has shown to be about that obtaining in the plowed layer in a seedbed.   In the case of North Platte soil the volume was 900 cc., which is equivalent to 70 pounds per cubic foot.   The

TABLE 1

Physical constants of Lincoln and North Platte soils used in nitrification studies

	LINCOLN SOIL	NORTH PLATTE SOIL
Hygroscopic coefficient.	9.2	8.3
Moisture equivalent.	25.6	20.8
Maximum water capacity (Hilgard's).	66.0	60.1
Mechanical analysis:		
Fine gravel.	0.0	0.0
Coarse sand.	0.1	0.1
Medium sand.	0.3	0.3
Fine sand.	1.7	3.3
Very fine sand.	33.0	62.0
Silt.	43.5	18.5
Clay.	21.4	15.8

TABLE 2

Chemical character of Lincoln and North Platte soils used in nitrification studies

	LINCOLN SOIL	NORTH PLATTE SOIL
	per cent	*per cent*
Organic matter (C $\times$ 1.724).	4.730	2.190
Nitrogen.	0.222	0.116
Inorganic CO_2.	0.030	0.010
Truog reaction.	Medium acid	Very slightly acid
Veitch reaction.	Alkaline	Alkaline

jar was covered with a square of loose muslin, weighed, and placed in the incubator.   At the time of filling the jars a sample of the wet soil was removed for nitrates and moisture.   On account of the large number of jars required it was not possible to run the incubations in duplicate.

Maintaining constant temperature

Several different types of incubators and constant temperature apparatus had to be pressed into service.   In the case of studies on moisture, a constant temperature room running at 25° was available.   For temperatures below 25°

the equipment of the department of plant pathology, described by Peltier (4) was afforded us.   For temperatures above 25°, in the case of the Lincoln soil, common incubators were used, but maintaining an incubator at 45° or 55° was found to be impractical and, for studies on North Platte soil, water thermostats were used.

In the experiments with Lincoln soil, the temperatures were read two or three times daily and recorded, hence the average departs somewhat from the temperature planned.   In the studies on North Platte soil the incubators and thermostats were maintained at the exact points desired.

Maintaining constant moisture

The jars of soil were weighed regularly and water was added as required to keep the moisture content constant within 0.5 per cent.   In the case of the temperatures 5°, 15°, and 25°, evaporation was very slight and adjustment of moisture was infrequent.   In the case of 45° and 55° the rate of evaporation was very high and the daily additions of water which were made were not sufficient to maintain moisture closer than 2 per cent of the desired wetness.   In the case of the soils at the hygroscopic coefficient and at one and one-half times the hygroscopic coefficient it did not seem proper to add water, as it would probably not become well distributed.   Consequently the constant temperature room was kept damp, and wet towels were kept over the jars.   This maintained constant moisture for the complete period.

Determination of nitrates

Nitrates were determined in quadruplicate or triplicate by the phenoldisulfonic acid method, which had been found to be quite reliable for Nebraska soils.   The technique employed at this station is as follows:

Weigh out 200 gm. of wet soil and place in an 8-ounce milk bottle.   At the same time weigh out a 200-gm. portion of soil for moisture determination.   To the bottle add a few drops of toluene and 250 cc. of distilled water and shake by hand, at intervals for one hour. Add 2 gm. powdered CaO and allow to settle.   Filter through nitrate-free filter paper, discarding the first runnings.   Transfer 10 cc. to an evaporating dish and evaporate to dryness on a water bath.   Allow the dish to cool and add 2 cc. phenoldisulfonic acid (Chamot's reagent) from a burette and flush quickly over the residue.   Allow to stand 10 minutes with frequent stirring and add 50 cc. distilled water.   Make alkaline with 12 N KOH and dilute to some multiple of 100 cc. in a graduated cylinder.   Read against freshly prepared standard in a Campbell Hurley colorimeter.

In the course of several thousand nitrate determinations made in connection with this study and others, we have made the following observations pertinent to the phenoldisulfonic acid method:

1. Soils for nitrate determinations should not be oven-dried.   Whenever possible the determination should be made on the field-wet soil the same day that the sample is taken.
2. When samples must be stored for several days before analysis, placing them on ice is probably better than adding toluene.

3. The nitrate procedure should be carried as far as evaporation to dryness, the same day that it is begun.

4. When field-wet soils are used, CaO is a satisfactory flocculent and gives water-white filtrates. The use of alum for clarification leads to low results.

5. The standard solution should be prepared fresh each day. The standard nitrate solution must be made alkaline before evaporation. It is our practice to add to 10 cc. of standard nitrate solution, 15 cc. of saturated lime water as suggested by Davis (1), before evaporation to dryness. Five or six standard determinations are checked against the previous day's standard and any one that is off is discarded, the others being mixed for the new standard.

6. When the sulfonated residue is diluted with 50 cc. of water no precipitation is obtained with KOH. Several workers have reported this precipitate with KOH when diluting with 15 to 25 cc. of water as customary with the ammonia method.

TABLE 3

Production of nitrate nitrogen at different temperatures in Lincoln soil

Initial content 4.0 p.p.m.; soil at moisture equivalent

TEMPERATURE	AFTER 1 DAY	AFTER 8 DAYS	AFTER 15 DAYS	AFTER 22 DAYS	AFTER 29 DAYS
°C.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
6.9	0.4	2.6	2.7	2.2	2.2
15.1	0.4	3.1	3.7	3.8	4.3
22.9	1.4	4.9	8.1	8.2	9.1
25.4	1.9	6.1	8.7	10.3	11.7
34.5	3.7	14.4	22.5	27.0	30.1
48.3	3.0	13.8	14.8	8.4	11.1
55.0	0.2	−1.5	−2.2	....	....

TABLE 4

Production of nitrate nitrogen at different temperatures in North Platte soil

Initial content 4.2 p.p.m.; soil at moisture equivalent

TEMPERATURE	AFTER 7 DAYS	AFTER 14 DAYS	AFTER 21 DAYS	AFTER 28 DAYS	AFTER 42 DAYS	AFTER 56 DAYS
°C.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
5	1.3	3.2	7.2	8.9	....	....
15	5.4	7.5	11.5	11.0	....	....
25	7.6	11.5	18.1	21.2	28.5	33.8
35	13.8	16.9	31.1	36.2	46.1	62.6
45	6.1	12.4	17.3	23.2	....	....
55	0.4	−0.5	−0.7	....	0.5*	....

* Obtained on a jar removed after 21 days and incubated for 21 days longer at 25°.

DATA

Effect of temperature on nitrate production

Tables 3 and 4 show the effect of temperature on nitrate production in Lincoln and North Platte soils respectively. In both cases the soil was maintained at constant moisture content equal to the moisture equivalent. The same data are presented in graphical form in figures 1 and 2, where nitric nitro-

gen is plotted against temperature. Each graph shows the nitric nitrogen found at the end of the period indicated for it in the figure. The rate of nitrate production is better shown in figures 3 and 4, where nitric nitrogen is plotted against the period of incubation.

The two soils respond to temperature changes in the same general way, but not to the same extent. Maximum production is attained at 35° in both soils; 45° is repressive, and 55° is excessive. Below 35° nitrate production is an exponential function of temperature, but differs considerably for the two soils.

Fig. 1. Effect of Temperature on Nitrate Production in Lincoln Soil Maintained at Constant Moisture Content Equal to the Moisture Equivalent

At 5° in North Platte soil considerable nitrates are produced, but at 7° in Lincoln soil nitrate production is insignificant. North Platte soil at 35° produces about a fifth more nitrates in a 3-week period than does Lincoln soil at the same temperature, and at 25° produces almost twice as much. At 5° North Platte soil produces as much nitrates in a 3-week period as Lincoln soil does in the same time at about 20°. In North Platte soil nitrate production proceeds at a more or less steady rate for the entire 8 weeks, but in Lincoln soil the rate of nitrification is slowed down at an exponential rate, and at the end of 4 weeks is very much retarded.
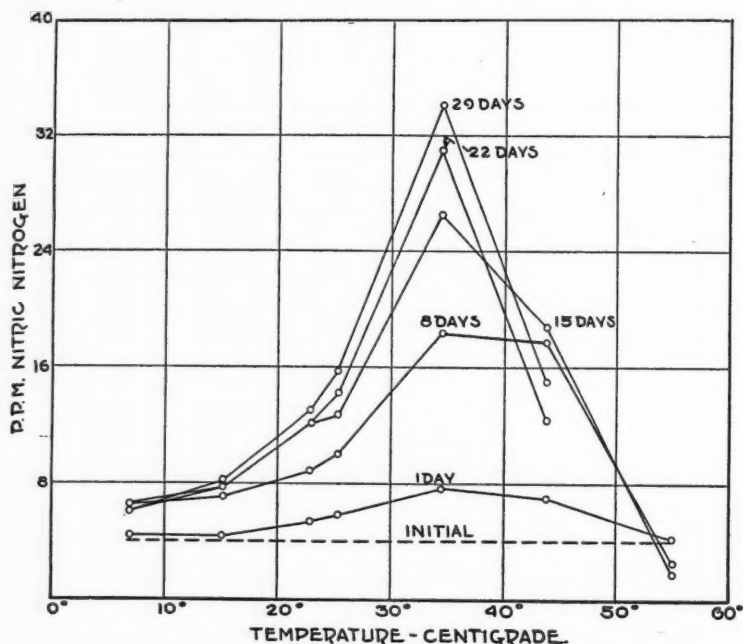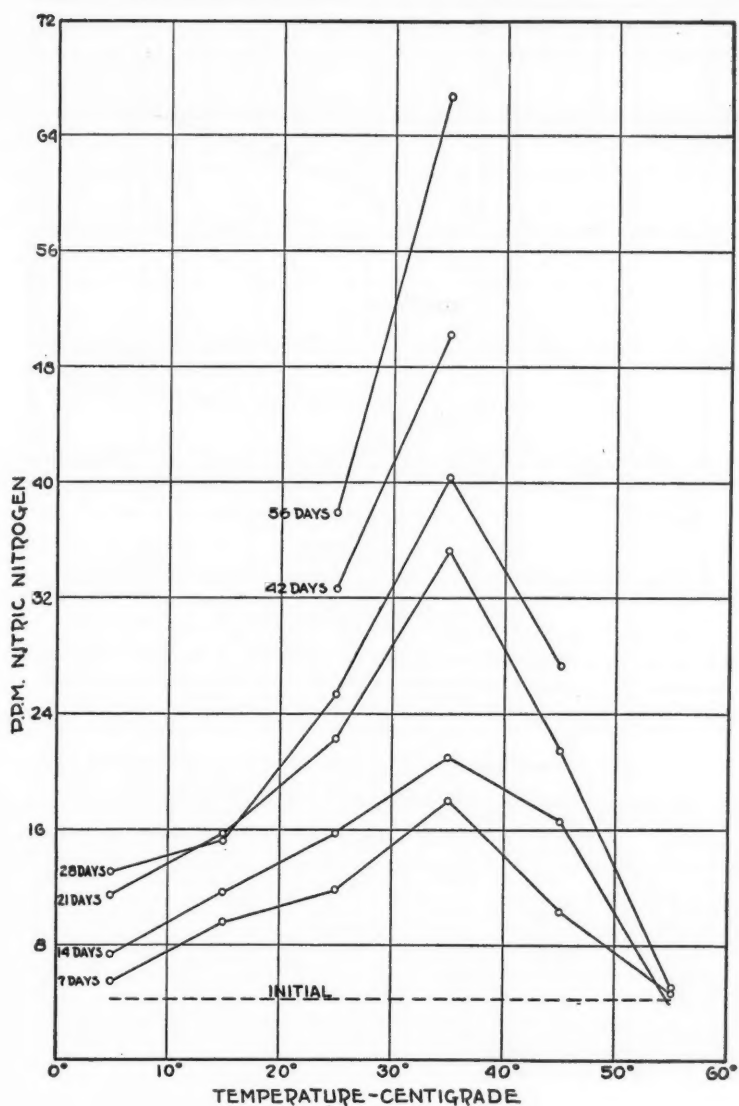
FIG. 2. EFFECT OF TEMPERATURE ON NITRATE PRODUCTION IN NORTH PLATTE SOIL MAINTAINED AT CONSTANT MOISTURE CONTENT EQUAL TO THE MOISTURE EQUIVALENT
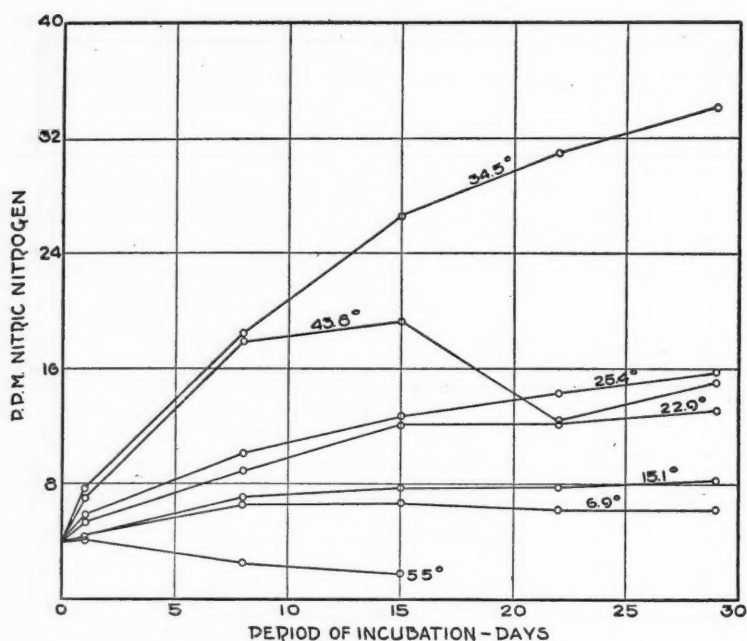
Fig. 3. Quantity of Nitric Nitrogen Found at the End of Different Periods in Lincoln Soil at Constant Moisture Content and Varying Temperatures

TABLE 5

Production of nitrate nitrogen at different moisture contents in Lincoln soil

Initial content 4.0 p.p.m.; soil at constant temperature of 23.9°C.

WETNESS	MOISTURE CONTENT	AFTER 1 DAY	AFTER 8 DAYS	AFTER 15 DAYS	AFTER 22 DAYS	AFTER 29 DAYS
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
H.C.*	9.2	0.0	0.9	2.3	1.4	1.3
1½ H.C.	13.8	1.2	2.4	3.3	2.8	2.8
2 H.C.	18.4	1.6	3.3	5.3	5.7	6.4
M.E.†	25.6	1.4	4.9	8.1	8.2	9.1
1¼ M.E.	32.0	0.6	0.7	9.6	15.4	11.4

* H.C. = hygroscopic coefficient.
† M.E. = moisture equivalent.

Effect of moisture on nitrification

Tables 5 and 6 show the effect of moisture on nitrate production in Lincoln and North Platte soils respectively. The same data are presented graphically in figure 5, where the nitric nitrogen found at the ends of the periods shown

on each graph, is plotted against moisture content. For convenience the multiples of the hygroscopic coefficient (H.C.) and moisture equivalent (M.E.) corresponding to the water contents used are indicated for each soil on the
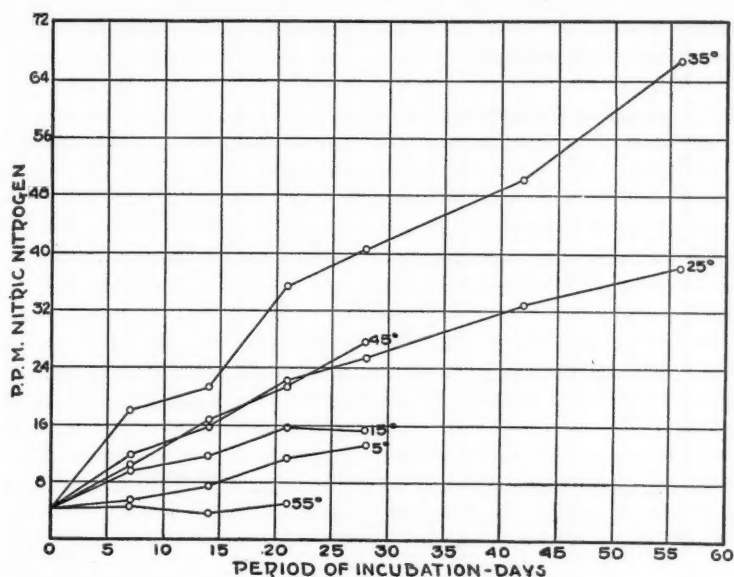
FIG. 4. QUANTITY OF NITRIC NITROGEN FOUND AT THE END OF DIFFERENT PERIODS IN NORTH PLATTE SOIL AT CONSTANT MOISTURE CONTENT AND VARYING TEMPERATURES

TABLE 6

Production of nitrate nitrogen at different moisture contents in North Platte soil

Initial content 4.2 p.p.m.; soil at 25°C.

WETNESS	MOISTURE CONTENT	AFTER 7 DAYS	AFTER 14 DAYS	AFTER 21 DAYS	AFTER 28 DAYS	AFTER 42 DAYS	AFTER 56 DAYS
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
H.C.*	8.3	0.0	1.3	2.3	1.9	....	....
1½ H.C.	12.5	7.8	9.9	13.3	12.3	....	....
2 H.C.	16.6	8.6	12.0	16.4	17.6	22.4	30.3
M.E.†	20.8	7.6	11.5	18.1	21.2	28.5	33.8
1¼ M.E.	26.0	10.6	13.6	21.0	25.6	36.1	53.9

* H.C. = hygroscopic coefficient.
† M.E. = moisture equivalent.

moisture axis. The two sets of graphs are not strictly comparable, for the studies on Lincoln soil were made at 22.9°C., while the studies on North Platte were made at 25°C. The data in table 4 would seem to indicate that the slope
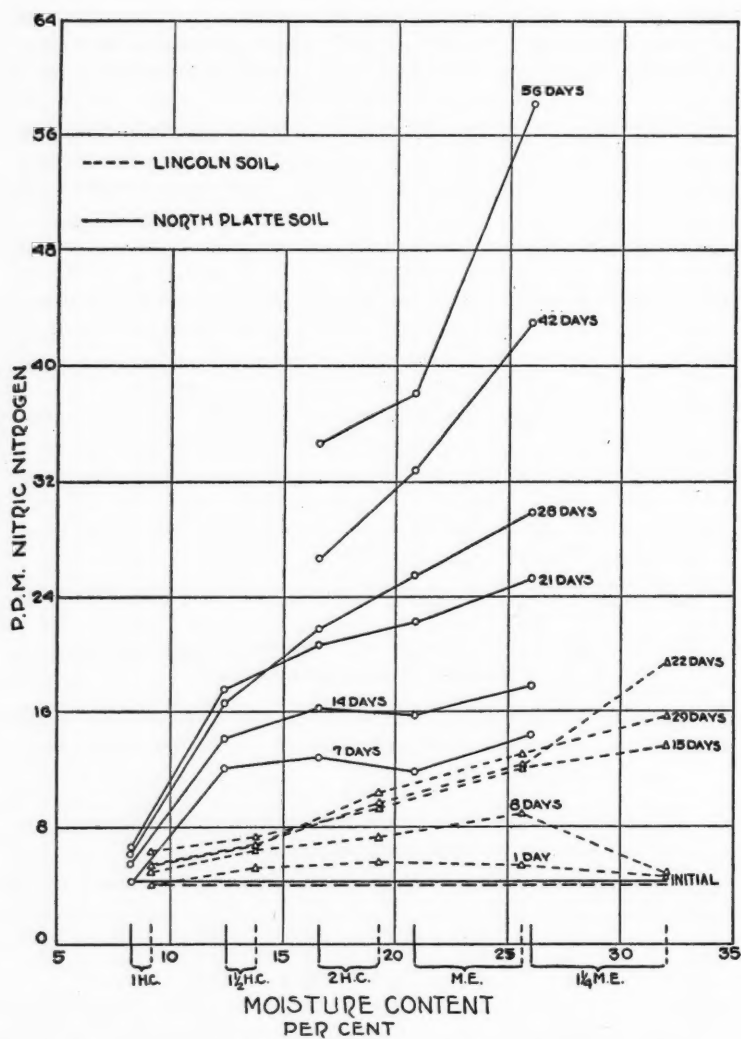
FIG. 5. EFFECT OF MOISTURE ON NITRATE PRODUCTION IN LINCOLN AND NORTH PLATTE
SOILS MAINTAINED AT CONSTANT TEMPERATURE

The broken lines throughout refer to the Lincoln soil and the solid lines to the North
Platte soil. The hygroscopic coefficient (H.C.) and the moisture equivalent (M.E.) and
their multiples at which studies were made are indicated for each soil. The two sets of
graphs are not strictly comparable since the temperature for Lincoln soil was 22.9° and
the temperature for North Platte soil was 25°.

of the graphs for Lincoln soil would be about 10 per cent greater had a temperature of 25°, instead of 22.9°, been employed.   This is taken into consideration in the interpretations that follow.   In both soils the effect of increasing the moisture up to one and one-fourth times the moisture equivalent is to increase nitrate production.   In both cases very little nitrate production occurs at the hygroscopic coefficient.   Probably that which did occur in the experiments was developed during the first few days before the moisture was well distributed throughout the soil mass, and while some granules were wetter than the hygroscopic coefficient.   Wetting Lincoln soil to one and one-half times the hygroscopic coefficient (13.8 per cent) increased nitrate production very little, but wetting North Platte soil to the same degree (12.5 per cent) stimulated nitrate production to a marked extent.   Beyond one and one-half times the hygroscopic coefficient, nitrate production bears a linear relation to moisture content, but differs widely for the two soils.   Almost as much nitrates are produced at one and one-half times the hygroscopic coefficient in 7 days in North Platte soil as are produced in 22 days in Lincoln soil at the moisture equivalent (25.6 per cent).   North Platte soil at the moisture equivalent (20.8 per cent) produced in 3 weeks, more than twice as much nitrates as did Lincoln soil at equivalent wetness in the same time.

The effect of moisture on nitrate production in these two soils is in general agreement with the findings of Greaves and Carter (2) within the range of moistures studied.   The highest moisture content used, one and one-fourth times the moisture equivalent, is 49 and 43 per cent of the maximum water capacity for Lincoln and North Platte soils respectively.   This wetness is probably somewhat below the point of optimum nitrate production.

Probable error

The large number of incubations required in the course of this study precluded the possibility of running incubations in duplicate, and the question arises concerning the probable accuracy of data based on single incubations. At various times, however, incubations have been run in duplicate, exactly the same technique of filling the jars, compacting, maintaining water content, etc., being employed in this study.   Table 7 shows the agreement between duplicates A and B in 28 such cases.   In only one case in 28 is the difference between duplicates greater than 1.0 p.p.m.   By calculating in percentage the departure from the average in each case, all are reduced to a common basis and the average deviation can be calculated.   The average deviation is 1.5 per cent.

The aeration factor in incubation studies

Probably the most uncertain factor in incubation studies is aeration.   At the outset of these experiments it was planned to give each soil in the incubation jar an identical and reasonable degree of compaction.   Later, special

studies were made to show the importance of the aeration factor in nitrification. Some of the data obtained with Lincoln soil are shown in tables 8 and 9 and substantiate the incubation technique employed. The so-called normal technique was to compact to an apparent specific gravity of 1.0, and cover the jar with loose muslin. Two other degrees of compactness are shown in table 8. In some cases the jars were sealed after filling. In other cases the jars

TABLE 7

Agreement between miscellaneous duplicate incubations and deviation from the average

A	B	AVERAGE	DEVIATION FROM AVERAGE
			per cent
4.2	4.4	4.30	2.3
4.5	4.5	4.50	0.0
4.4	4.8	4.60	4.3
6.1	6.2	6.15	0.8
6.3	6.8	6.55	3.8
6.4	6.7	6.55	2.3
6.7	6.8	6.75	0.7
6.7	7.1	6.90	2.9
6.9	7.2	7.05	2.1
12.1	12.4	12.25	1.2
12.6	12.7	12.65	0.4
12.9	13.1	13.00	0.8
12.9	13.5	13.20	2.3
13.2	14.1	13.65	3.3
13.3	13.9	13.60	2.2
15.1	15.5	15.30	1.3
15.3	15.4	15.35	0.3
15.5	15.8	15.65	1.0
15.7	16.9	16.30	3.7
16.0	16.2	16.10	0.6
16.2	16.4	16.30	0.6
16.7	16.7	16.70	0.0
17.1	17.6	17.35	1.4
17.3	17.4	17.35	0.3
18.6	18.6	18.60	0.0
20.6	20.8	20.70	0.5
22.0	22.4	22.20	0.9
22.9	22.7	23.30	1.7
Average..			±1.5

were sealed with a lid bearing a tubulature; 10 to 50 per cent of the air was withdrawn each day by suction, and fresh air was allowed to enter the jars. These data are shown in table 9. In all cases duplicates in normal technique check satisfactorily and show consistent results. Additional aeration where the soil was not compacted so much in the jar or where fresh air was provided each day, did not lead to any change in nitrate production. It is only when

TABLE 8

Production of nitric nitrogen in Lincoln soil under different conditions of packing

Period of incubation 21 days

PACKING	SPECIFIC GRAVITY	AT 1⅔ x H.C.*		AT M.E.†	
		25°	35°	25°	35°
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
Loose.............................	0.8 {	6.3		12.9	
		6.8		13.5	
Average.................................		6.6	22.8	13.2	35.8
Normal..........................	1.0 {	6.4		12.9	
		6.7		13.1	
Average..................................		6.6	21.6	13.0	34.6
Tight.............................	1.2 {	6.1		1.0	
		6.2		8.5	
Average..................................		6.2	20.9	4.8	15.4

* H.C. = hygroscopic coefficient.
† M.E. = moisture equivalent.

TABLE 9

Production of nitric nitrogen in Lincoln soil, wet to the moisture equivalent, under different conditions of aeration

AERATION	INCUBATED AT 25°C.				INCUBATED AT 35°C.
	1 week	2 weeks	3 weeks	4 weeks	
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Sealed........................... {	4.2	2.7	13.4	1.0	
	4.5	8.0	13.6	13.7	
Average........................	4.3	5.4	13.5	7.4	....
Normal.......................... {	4.2	6.9	12.9	16.2	
	4.4	7.2	13.1	16.4	
Average........................	4.3	7.1	13.0	16.3	34.6
Aerated 1/10 daily.............. {	4.5	6.7	13.3	15.1	
	4.5	6.8	13.9	15.5	
Average........................	4.5	6.8	13.6	15.3	34.9
Aerated 1/2 daily............... {	4.4	6.7	13.2	15.7	
	4.8	7.1	14.1	16.9	
Average........................	4.6	6.9	13.7	16.3	35.2

the jars were sealed or the soil compacted tightly that irregular and inconsistent results were obtained. The conclusion can be drawn that the data on the effects of temperature and moisture are not subject to any considerable errors on account of the aeration factors.

<div align="center">PRACTICAL APPLICATION</div>

In all sections where nitrate production is an important factor in crop performance, and where one of the objectives of seedbed preparation and cultivation is the elaboration of available nitrogen, the temperature and moisture conditions in the soil would seem to be of concern. This should be particularly the case on soil similar to the Lincoln soil reported in this study, where nitrate production is slow at low temperatures and low moisture contents. During the fall of the year when the seedbed is being prepared for winter wheat the soil temperature is generally high enough for rapid nitrate accumulation, but soil moisture conditions are likely to be unfavorable, either on account of weed growth or insufficient rainfall. Early plowing when the soil is moist, followed by harrowing and discing, which would put the furrow slice in condition to retain its moisture, would lead to greater nitrate accumulation than later plowing when the soil is dry. Soil that had been dried down to the hygroscopic coefficient by weeds and exposure might lie after plowing for weeks without accumulating any nitrates if rains did not come. At the end of a 4-week period Lincoln soil at one and one-half the hygroscopic coefficient developed not more than 2.8 p.p.m. nitric nitrogen. This would be equivalent to only 5.6 pounds in the surface 2,000,000 pounds of an acre of soil. When at the moisture equivalent, the same soil developed the equivalent of 18.2 pounds of nitric nitrogen per acre in the same period.

After winter wheat is seeded, soil temperature and moisture conditions may be more or less favorable for nitrate elaboration for a period, but when the soil temperature drops below 15° (60°F.) nitrate production slows down and later practically ceases, to be resumed again in the spring only when the soil begins to get warm.

Nitrates are produced at a very slow rate in such soil as the Lincoln soil used in this study when the temperature is below 12° or 15°C. (55°–60°F.). In the springtime if the season is much delayed, nitrates may not be produced at a rate adequate to meet the demands of the crop. Thus in Lincoln soil at 15° about 4.0 p.p.m. of nitric nitrogen are produced in a 4-week period under optimum water conditions and less if the soil is somewhat dry. This is equivalent to about two pounds per acre per week. A 30-bushel crop of wheat requires 50 pounds of nitric nitrogen. If little or no nitrates were available at seeding time, and if in the spring the soil averaged no higher in temperature than 15° (60°F.) for an 8- or 10-week period, only 16 to 20 pounds of nitric nitrogen would be developed which would be sufficient for only 10 to 12 bushels of wheat per acre. It would seem that in such soil, either tillage methods should be used which would insure adequate nitrates at seeding time, or efforts should

be directed toward improving the nitrification rate of the soil.   On soils such as the North Platte soil used in this study, nitrate elaboration at 15° is quite adequate.   Thus in 4 weeks at 15° under optimum water conditions 11.0 p.p.m., equivalent to 32 pounds per acre, of nitric nitrogen are produced, and in 8 or 10 weeks of spring weather with the soil averaging 15° enough nitrates would be developed to produce a 30-bushel crop of wheat without any supply being in the soil at seeding time.

In the case of corn and other inter-tilled crops which make their growth during the summer season, the soil is warm and the tillage which is given tends to maintain optimum moisture conditions at the surface.   Hence it is not remarkable that such crops do not usually suffer for lack of nitrates except where soil is thin or weeds are thick.   Excess of nitrates in the soil after the corn crop is mature is to be expected frequently.

The climatic factors which affect nitrate production differ in various sections of the country.   Soils also differ in their inherent nitrification responses to such factors as temperature and moisture, probably to a wider extent than is indicated by the two soils in this study.   Soils also differ widely in their nitrification responses to such factors as organic matter, aeration, and reaction. In experiments in various sections, the conclusions as to the functioning of tillage in nitrate elaboration can also be expected to differ.

SUMMARY

1. In this paper are reported studies on the effect of temperature and moisture on nitrate production in two typical Nebraska soils.   The temperatures studied ranged from 5° to 55°C.   The moisture contents studied ranged from the hygroscopic coefficient to one and one-fourth times the moisture equivalent.

2. Nitrate production is comparatively slow at 5°.   As the temperature is raised the rate of nitrate production increases rapidly.   At 35° nitrate production is at a maximum.   Above 35° nitrification becomes slower, and ceases altogether at 55°.   These conclusions are in agreement with the observations of Schloesing and Müntz in 1879.

3. Nitrate production is insignificant at moisture contents as low as the hygroscopic coefficient, but increases with the moisture content up to the highest degree of wetness studied, one and one-fourth times the moisture equivalent.

4. There are significant differences in the quantity of nitrates produced in the two soils under the same conditions of temperature and moisture.   North Platte soil from western Nebraska produces as much nitrates at 5° in a 3-week period as Lincoln soil from eastern Nebraska does in the same time at about 20°, and as much in 7 days at a wetness of one and one-half times the hygroscopic coefficient as Lincoln soil does in 22 days at the moisture equivalent.

5. Temperature and moisture conditions may be important considerations in nitrate elaboration in the field.   Low soil moisture content may interfere

with nitrate production during the wheat seedbed preparing season, and low soil temperatures may interfere with nitrate production during the spring when wheat is making its growth.   It is estimated that with an average soil temperature of 15° (60°F.), prevailing for 8 to 10 weeks during the spring, only enough nitrates can be elaborated for 10 to 12 bushels of wheat on Lincoln soil, whereas under the same conditions on North Platte soil, enough nitrates would be elaborated to produce 30 bushels of wheat.   Summer temperature and moisture conditions are favorable to a nitrate elaboration sufficient for such crops as corn, except where the soil is extremely thin.

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SOME FACTORS INFLUENCING THE SOLUBILITY OF PHOS-PHORUS IN SOIL—ACID PHOSPHATE MIXTURES

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The extent to which phosphorus applied to soils in fertilizers remains soluble in the soil solution is of direct economic significance to agriculture, and a knowledge of the soil factors influencing the solubility of phosphorus in soils has intrinsic value; because by means of this knowledge phosphorus fertilizers may be improved or methods may be devised whereby the application of phosphorus fertilizers to soils may be made more profitable.

When soluble phosphates are applied to soils some of the phosphorus contained in them reverts to less soluble forms. As a result of numerous researches designed to supply information on the subject of phosphorus solubility in soils and the plant-growth correlations, the explanations given for the fixation of phosphorus in soils may be summarized briefly as follows: (*a*) the presence in soils of magnesia, lime, and carbonate of lime; (*b*) the presence of iron and aluminum compounds, particularly in acid soils; (*c*) the presence of organic matter; (*d*) adsorption due to surface phenomena; and (*e*) bacterial action. Several investigators have shown that soil phosphorus, and the phosphorus of fertilizers applied to soils, may be held in a more soluble condition by the application of soluble fertilizer salts other than phosphates, and also by the action of soil bacteria (1).

The primary object of this paper is to show that soil factors other than those already enumerated may influence the solubility of phosphorus applied to soils in the form of $CaH_4(PO_4)_2$ or acid phosphate; and also to point out some important relationships between the several factors discussed and their effects on phosphorus fixation and solubility in soils.

EXPERIMENTAL

In order to study the effects of the soil bases calcium, magnesium, and potassium, separately, on the solubility of phosphorus applied to the soils as $CaH_4(PO_4)_2$, the natural, active bases of the soils were exchanged for the calcium, magnesium, and potassium of the corresponding chlorides by treating the soils, separately, with solutions of $CaCl_2$, $MgCl_2$ and KCl. By means of this substitution of bases the several soil bases are removed, to a certain extent, and a single known base substituted for them. If a strong salt solution is used to fix a base in a soil the reaction will proceed far enough to give the soil

399

certain distinct properties traceable to the base fixed.   In like manner a series
of soils may be placed on a comparative basis with respect to kind and quantity
of the fixed base, and the effects of this base may be studied in various ways,
and compared with the effects of other bases similarly fixed.

For part of the experimental work four sandy loam surface soils were
selected as follows: (a) Rodman sandy loam containing limestone, pH 7.54;
(b) Bellefontaine sandy loam, pH 7.02; (c) Fox sandy loam, pH 5.73; and (d)
Fox sandy loam, pH 4.75.   The reaction of these soils is designated as alkaline,
neutral, medium acid, and strongly acid in the order named and on a com-
parative basis.   Soils of one textural class were taken in order to eliminate
differences which might be due to dissimilarity in mechanical composition.
The soil samples were prepared for the several treatments by passing the air-
dried soil material through a 2-mm. mesh round-hole sieve and thoroughly
mixing the screened soil before using it.

In order to keep the soils on a comparative basis from the standpoint of
quantities of bases fixed in them from the neutral salts, it is necessary to deter-
mine the amounts of active bases present in the soils when in their natural,
untreated condition.   A numerical factor for this quantity of active base
present in each soil is obtained in the following manner:

Twenty grams of air-dried soil are placed into an 8-ounce sterilizing bottle and 50 cc. of a
0.2 N HCl solution added.   The bottle and contents are shaken for 3 hours.   The solution is
then separated from the soil mass by filtration and 25 cc. drawn from the filtrate, boiled to
expell CO_2, and titrated to the neutral point for excess acid.   The quantity of HCl neutral-
ized by the soil bases, not including iron and aluminum, is determined by difference and its
equivalent in bases computed as calcium (2).

These quantities of active bases in terms of calcium per 2,000,000 pounds of
soil, and for all the soils used in connection with this work, are given in table 1.
The quantities of iron and aluminum given were also determined in this HCl
solution.

In like manner the equivalents of active bases, as calcium in 40 gms. of soil,
were determined for the four sandy loam soils under investigation.   Forty
grams of these soils were treated with solutions of $CaCl_2$, $MgCl_2$, and KCl in
quantities of 10 equivalents of salt in 100 cc. of solution for 1 equivalent of
active base found in 40 gms. of soil.   Each soil sample was treated with only one
salt.   After standing one hour, the solutions were filtered from the soils which
were washed with CO_2-free distilled water until quite free of chlorides.   The
soils were then air-dried, treated in 8-ounce sterilizing bottles with the desired
quantity of $CaH_4(PO_4)_2$ solution, allowed to stand 1 hour with stirring, brought
to a liquid volume of 100 cc. with distilled water, and shaken constantly for
7 hours.   The untreated and phosphate-treated check samples were also washed
with the same quantities of distilled water as were used for the salt-treated
samples.   After being shaken, the soil samples were centrifuged and the slightly
cloudy solutions placed into Erlenmeyer flasks and allowed to stand until 50-cc.

TABLE 1

Solubility of phosphorus, pH values, and content of bases estimated as calcium, also iron plus aluminum, soluble in 0.2 N HCl

The treated soil portions received 3.84 mgm. of P_2O_5 in mono-calcium phosphate. Bases, and iron plus aluminum are reported as pounds per 2,000,000 pounds of soil.

SOIL NUMBER	SOIL TYPE	P_2O_5 IN SOLUTION		pH VALUES		BASES AS Ca	Fe_2O_3 Al_2O_3
		Not Treated	Treated	Not Treated	Treated		
		mgm.	*mgm.*			*pounds*	*pounds*
d	Fox sandy loam................	.....	.....	4.75	4.78	880	5,540
12	Genessee silt loam..............	.....	tr.	7.30	6.98	9,440	7,120
10	Napanee silty clay loam.........	tr.	tr.	6.59	6.44	7,840	6,300
14	Fox sandy loam................	tr.	0.248	5.11	4.92	1,440	5,800
11	Napanee silt loam..............	0.186	0.248	5.68	5.65	6,400	6,360
27	Napanee loam..................	0.186	0.308	5.29	5.22	3,920	6,580
32	Miami loam....................	0.248	0.370	7.00	6.81	9,120	7,880
21	Bellefontaine sandy loam........	0.308	0.370	5.17	5.10	2,720	4,560
19	Waukesha loam.................	0.248	0.370	5.04	4.90	4,000	6,400
9	Napanee silt loam..............	0.308	0.432	5.75	5.66	3,680	7,380
4	Bellefontaine loamy sand........	0.186	0.432	5.19	5.02	640	5,100
c	Fox sandy loam................	.....	0.494	5.73	5.32	2,000	6,820
2	Brookston clay loam............	0.248	0.494	6.80	6.68	11,840	9,400
5	Fox sandy loam................	0.248	0.494	5.41	5.32	1,920	5,560
13	Fox loam......................	0.370	0.494	5.34	5.29	1,840	5,040
26	Plainfield sand.................	0.248	0.494	4.94	4.97	560	3,400
29	Bellefontaine sandy loam........	0.308	0.494	5.00	5.04	1,120	4,360
31	Fox sandy loam................	0.370	0.494	5.11	5.05	960	3,460
23	Fox sandy loam................	0.494	0.556	5.11	4.61	560	4,220
16	Fox sandy loam................	0.494	0.680	5.02	5.00	1,040	4,660
8	Waukesha loam.................	0.370	0.680	4.77	4.78	4,000	7,640
1	Bellefontaine sandy loam........	0.494	0.742	5.73	5.34	1,200	3,920
15	Waukesha loam.................	0.556	0.742	6.20	5.71	5,040	5,520
20	Bellefontaine sandy loam........	0.618	0.742	5.70	5.72	2,160	5,180
24	Fox sandy loam................	0.680	0.866	5.68	5.61	1,200	4,020
3	Bellefontaine sandy loam........	0.370	0.928	5.39	5.36	1,520	3,000
25	Plainfield loamy sand...........	0.618	0.928	5.22	5.26	800	4,540
30	Bellefontaine sandy loam........	0.680	0.928	5.38	5.34	720	3,940
18	Bellefontaine sandy loam........	0.742	0.990	5.19	5.00	1,120	3,620
28	Waukesha loam.................	0.742	1.050	5.04	5.14	4,240	6,040
a	Rodman sandy loam............	0.494	1.112	7.54	7.39	6,960	6,380
17	Bellefontaine sandy loam........	0.990	1.236	5.44	5.41	1,040	5,120
b	Bellefontaine sandy loam........	0.370	1.360	7.02	6.37	2,960	6,520
6	Plainfield sand.................	0.928	1.360	5.95	5.80	1,440	4,400
22	Bellefontaine sandy loam........	0.360	1.730	5.65	5.66	4,560	7,140
7	Bellefontaine sandy loam........	0.866	1.978	5.85	5.44	2,720	6.960

portions of clear liquid could be drawn off. The phosphorus determinations
were made on these clear solutions.

The effects of treating the soils with neutral salts on the fixation and solubility of phosphorus added to them as $CaH_4(PO_4)_2$ are illustrated graphically
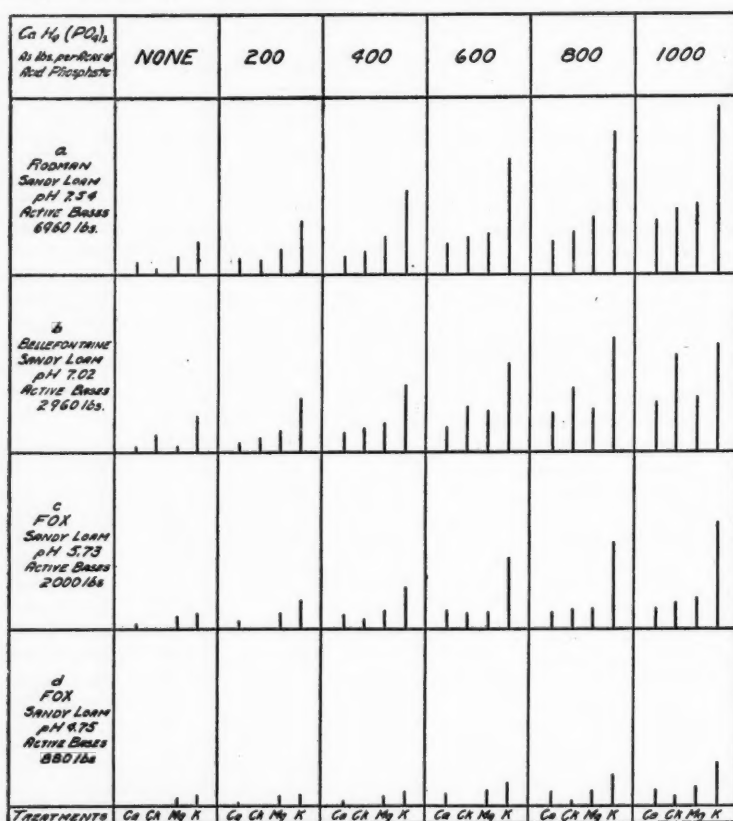in figure 1, where the vertical lines represent comparative solubilities of P_2O_5

FIG. 1. COMPARATIVE SOLUBILITIES OF P_2O_5 FOR VARIOUS QUANTITIES OF PHOSPHATE
ADDED TO THE DIFFERENT CHECKS AND SALT-TREATED SOIL SAMPLES

for various quantities of phosphate added to the different checks and salt-treated soil samples.

A miscellaneous series of soils was also studied in order to determine changes
in phosphorus solubility between the natural soils and those to which
$CaH_4(PO_4)_2$ was applied at the rate of 600 pounds of 16 per cent acid phosphate
per 1,000,000 pounds of soil. The pH values were found on the treated and

untreated soils, and the active bases, and iron plus aluminum were determined by solution in 0.2 N HCl as previously described. Table 1 contains these data arranged in order of increasing quantities of water-soluble P_2O_5 found in the phosphate-treated soils.

DISCUSSION

Considering the data in figure 1, we have some clear illustrations of the factors influencing the fixation and solubility of phosphorus in the soils used and under the conditions of the experiment; and in addition we may draw some valuable conclusions from the results presented. Phosphorus solubility in each soil is proportional to the quantities of phosphorus applied, and is also proportional to the power of the different soils to fix the bases of the neutral salts, as is shown by the quantities of active bases in these soils in relationship to their reaction. This last statement, however, does not apply to natural untreated soils as is shown by the results given in table 1 where no general correlation exists between active bases and quantities of P_2O_5 fixed by the soils; because in natural soils we have to deal with a mixture of several bases as well as other important factors, but in the experiment under discussion we are dealing with one-base soils. The quantities of soluble phosphorus found are also in the same order or magnitude as the solubilities of the di-phosphates and tri-phosphates of calcium, magnesium, and potassium. The fact that the phosphorus solubilities are proportional to the quantities of bases fixed by the different soils, and are also in the same order as the solubilities of the corresponding phosphates of these bases, is considered evidence that the phosphates of these bases are formed in the soils.

The KCl treatments increased the solubility of phosphorus applied as $CaH_4(PO_4)_2$ over the checks in all cases. Similar effects may be expected from NaCl treatments because of the high solubility of the sodium phosphates.

Except in the case of the neutral soil, the $MgCl_2$ treatments also increased the solubility of phosphorus applied as $CaH_4(PO_4)_2$ over the checks. The results obtained after the $MgCl_2$ treatments on the neutral soil may be due to the exchange of sodium and potassium bases of the soil for magnesium of the salt, thus causing the formation of a less soluble magnesium phosphate.

In the case of the alkaline and neutral soils, the $CaCl_2$ treatments decreased the solubility of the applied phosphorus over the checks; but in the two acid soils, excepting the 800- and 1000-pound applications in terms of acid phosphate on the medium acid soil, the $CaCl_2$ treatments increased the solubility of the applied phosphorus. If a degree of soil reaction exists above which the fixation of calcium decreases the solubility of applied phosphorus when compared with the natural soil, and below this point increases the phosphorus solubility, as these results appear to show, this knowledge should be of practical importance.

When $CaH_4(PO_4)_2$ is applied to soils with pH values above about 5.5, depending somewhat upon the concentration of the phosphate solution, $CaHPO_4$

C. H. SPURWAY

and also $Ca_3(PO_4)_2$ if the supply of calcium base is sufficient, are undoubtedly precipitated in the soil, part of the phosphate fixation being due to this action. Under similar conditions $MgHPO_4$ and $Mg_3(PO_4)_2$ could also be formed by the soil base magnesium. It cannot be stated, positively, however, whether or not these phosphates are formed in acid soils having pH values below 5.5, but if formed, they can be present in only small quantities and do not account for the insolubility of the phosphorus in the most acid soil. That a phosphorus compound of less solubility than a calcium phosphate is formed by treating the strongly acid soil with $CaH_4(PO_4)_2$, is evident from a comparison between the checks and the $CaCl_2$ treatments on this soil.

Another point of practical importance to agriculture may be emphasized further by the results under discussion. Applications of sodium or potassium fertilizing salts to soils made previously to, or possibly at the same time as, applications of soluble phosphate fertilizers should hold this applied phosphate in a more soluble condition. On the other hand, the effects produced in the soil by the use of calcium or magnesium salts together with soluble phosphates will depend on the chemical nature of the soils to which these compounds are applied. In this connection, the soil reaction and the quantity and proportion of active soil bases present will play an important part.

Table 1 shows no general correlation between pH values, active bases as determined by the method described and iron and aluminum collectively, and phosphorus fixation or solubility in these soils. A relationship is indicated however, between the quantities of water-soluble phosphorus found in the untreated soils and that found in the same soils treated with $CaH_4(PO_4)_2$ at the rate of 600 pounds of acid phosphate per 1,000,000 pounds of soil. In the majority of the soils studied, high solubility of soil phosphorus is accompanied by high solubility of the applied phosphorus. Where there is a noticeable change in the soil reaction produced by adding the $CaH_4(PO_4)_2$, the soils are made more acid.

It is also evident from these results that it will be difficult to correlate fixation and solubility of applied phosphorus with any one soil factor; but a number of factors must be considered which will give a different resultant for each soil. It may be seen from the data presented here that hydrolyzing potassium or sodium soil bases will hold the phosphorus applied as acid phosphate more soluble in the soil than the hydrolyzing bases calcium or magnesium, the reverting power of calcium being greater than magnesium. The total or resultant effect will depend upon both the quantity and proportion of the several hydrolyzing soil bases. In acid soils where the proportion of hydrolyzing bases to acids greatly decreases, other factors come into prominence resulting in the formation of very insoluble phosphorus compounds.

A determination of the relative solubility of phosphorus in soils treated with acid phosphate or any other soluble phosphate can easily be made, and the results checked with field experiments in order to ascertain the importance of the solubility of soil phosphorus in relation to applied phosphorus and its effect

on crop production. The importance of devising means of treating soils in a manner designed to prevent the reversion of applied phosphates, or of developing phosphorus fertilizers that will not revert to less soluble forms when applied to soils will thus become apparent by comparing field results with the soil factors known to influence the fixation and solubility of phosphorus in soils.

SUMMARY

When four sandy loam soils of different degrees of reaction and containing different quantities of active bases are placed on a comparative basis by substituting for their active soil bases the base radical of $CaCl_2$, $MgCl_2$ and KCl, separately, the solubility of phosphorus applied to them as $CaH_4(PO_4)_2$ in various amounts is proportional to the quantities applied, to the quantities of bases fixed in the soils, and in the order calcium, magnesium, potassium— evidence that the phosphates of these bases are formed in the soils.

The KCl treatments increased the solubility of the applied phosphorus over the checks in all cases; the $MgCl_2$ treatments increased the phosphorus solubility in all cases except three; and the $CaCl_2$ treatments decreased the solubility of the phosphorus in the neutral and alkaline soils, and increased it in the acid soils except in three cases of heavy phosphate applications.

In some soils it appears that the soil factors regulating the solubility of natural soil phosphorus have the same influence on the solubility of applied soluble phosphorus.

The quantity and proportion of hydrolyzing soil bases are important soil factors that influence fixation and solubility of phosphorus in soils.

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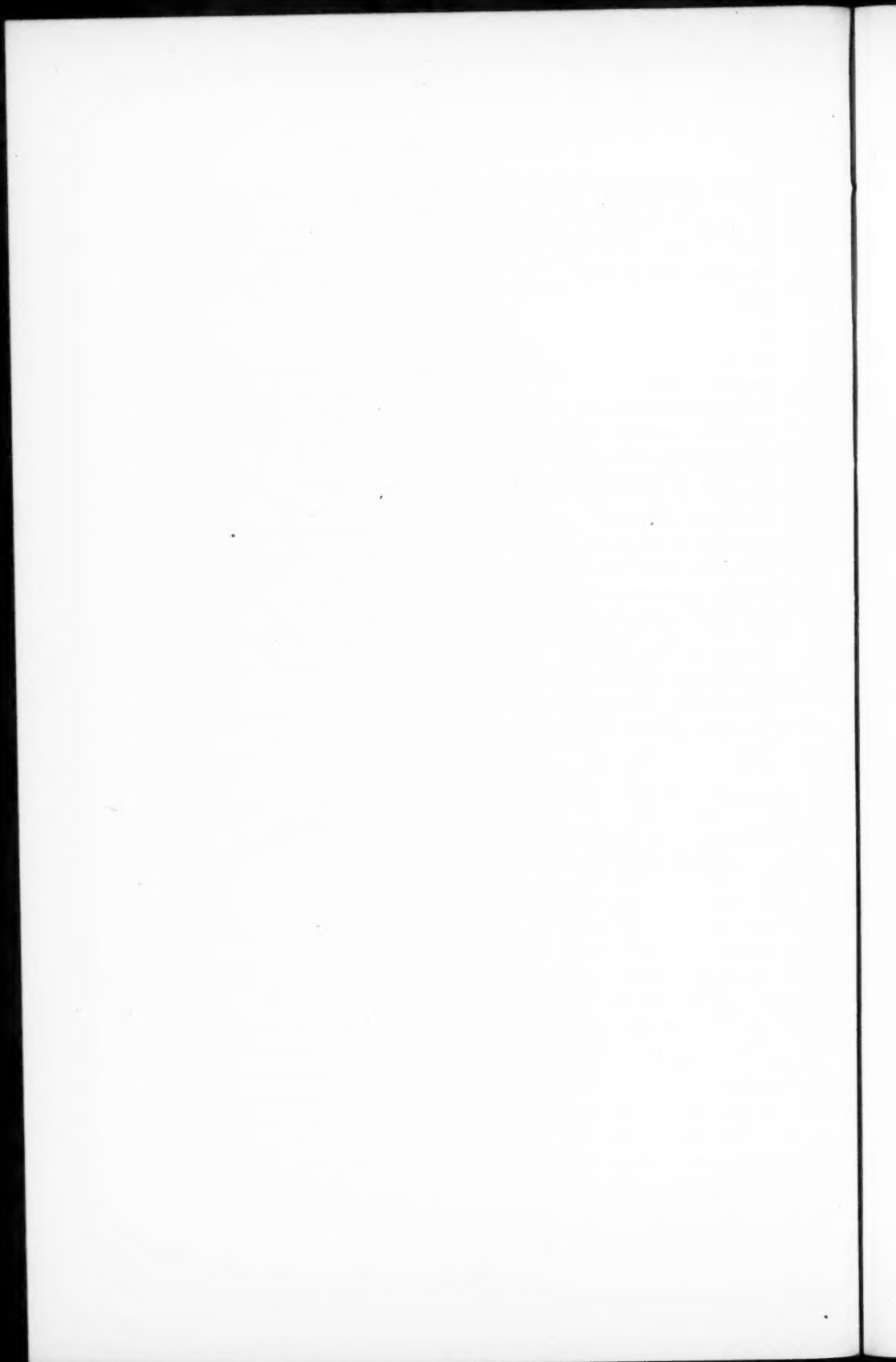
SOIL COLLOIDS AS SIMPLE SUSPENSIONS

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While conducting a study on the effect of certain salts on rate of percolation through heavy subsoils, it was noticed that the rate varied from day to day. According to a recording thermometer, the temperature of the laboratory in which this work was being done also fluctuated over a range of 15°F. in 24 hours.

Bouyoucos (3) in studying the effect of temperature on the percolation of water in soils, found that as the temperature increased from 0° to 50°C. the rate of percolation through sands increased almost as a linear function of the temperature. While with the other soils studied, sandy loam, silt loam, clay and muck, he found a marked increase in rate of percolation up to 30° to 40°C. followed by a very sharp decrease at higher temperatures. This decrease in the case of clay was from about 25 gm. percolate in 30 minutes at 30°C. to about 17 gm. percolate in 30 minutes at 50°C. He accounted for this decrease as follows:

Evidently, there appears to be some other factor or factors which are influenced more predominately by temperature than the viscosity of water, and succeed, partially or completely in over-powering the effect of the latter. These opposing factors are to be found (3) in the swelling of the colloidal material present in the soil and in the change in structure of the soil mass, with increase in temperature. . . . . Now it is also known that colloidal substances swell when they absorb water, and that this property of swelling increases with temperature. . . . . As the temperature rises . . . . the colloidal material swells. . . . . When a certain temperature is reached, however, the increase in volume due to swelling of colloids subjects the mass to a strain and many of the pore spaces are closed. . . .

Since the temperature of the laboratory in which this work was done, never went above 30°C., an attempt was made, according to the suggestions of Bouyoucos, to correlate the rate of percolation with the temperature changes, especially on the basis of changes in the viscosity of water. No relation was evident. The soil used in this work contained a high percentage of colloidal material. Consequently the assumption naturally followed that the observed irregularities in percolation might be due to such phenomena as suggested by Bouyoucos, viz., the swelling of the colloids and the closing of the channels through the soil.

If the explanation as offered by him is correct, then by using the viscosity change of colloids separated from the soil as a measure of their swelling activi-

407

ties, one should expect that the viscosity changes of colloids would be insignifi-
cant below 30° or 40°C. but become significant above these temperatures;
because according to Alexander (1) "increase in viscosity accompanies the
hydration and swelling of the particles."

To test the validity of this theory of colloidal swelling with rise in tempera-
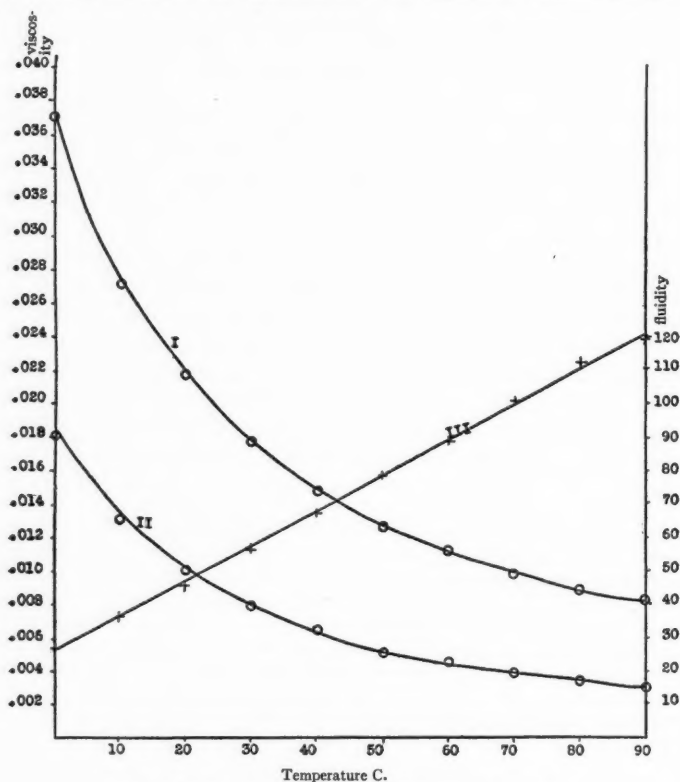ture, colloidal material was separated from the subsoil of Putnam silt loam by

Fig. 1. Fluidity and Absolute Viscosity Curves

I.   Absolute viscosity curve, 6 per cent colloid
II.   Absolute viscosity curve of water
III. Fluidity curve of 6 per cent colloid

means of the supercentrifuge, the method developed by Bradfield (4) being
used.   The viscosities of the colloidal solution containing 6 per cent dry matter
by weight were measured by 10-degree intervals, in a Washburn viscometer
submerged in a thermostat, for a range in temperature from 0° to 90°C. inclu-
sive.   The temperatures were regulated to within 0.5°C.   Ample time was
allowed for them to become constant.   All results are averages of three read-

ings of which the maximum variation was never greater than one second. The data are presented in the form of curves with the absolute viscosities represented on the ordinate and the temperature on the abscissa.

The outstanding feature of the data is the fact that the absolute viscosity curve of the colloidal solution is a smooth one. It shows no abnormalities over the temperature range employed and is closely similar to the absolute viscosity curve of water as calculated from the table given by Bingham (2). Exactly similar data for the viscosity of colloidal solution were obtained by making the temperature changes in the reverse order.

If the colloid had shown marked swelling at 30° to 40°C., as suggested by Bouyoucos, then the curve should have shown a marked change of slope near these temperatures. It had none whatsoever. The viscosity curve of the colloid at higher temperatures approaches that of water, suggesting that as the temperature increased the colloid material had a lessened relative effect on the viscosity of water.

As pointed out before, these results were duplicated by taking the temperatures in reverse order. Bouyoucos found his percolation rates with decreasing temperatures different from those with increasing temperatures.

To test further this theory of swelling, the fluidity curve of the colloid under the different temperatures was plotted. It takes the form of a straight line as shown in connection with the viscosity curves. According to Bingham (2) this is the case for a true suspension, and suggests that for this colloid, over the temperatures used, as for a suspension in general, the fluidity curve is a linear function of the temperature. According to these results, it seems evident that the swelling of the colloids is insignificant over the temperature range used and certainly cannot be a contributor to the variation in rate of percolation in this case.

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